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30MM GAU-8/A PLASTIC FRANGIBLE PROJECTILE ,

AD B027446

10 Roy B. Steidley

DeBELL & RICHARDSON, INC.
DIVISION OF SPRINGBORN LABORATORIES, INC.
ENFIELD, CT 06082

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A 30mm target practice (TP) projectile, designed to break up on impact with the earth, has been developed for the GAU-8/A aircraft cannon. The projectile consists of a stack of steel washers supported by a central steel tube and encapsulated by and bonded to an outer shell of fiber glass reinforced nylon 12 plastic. A fiber glass reinforced nylon 12 plastic nose, which is molded onto the projectile through the central tube, closes one end of the projectile. A steel end cap, bonded to the outer plastic shell, closes the (over)

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other end. The projectile has been demonstrated to remain intact through an extensive series of single shot gunfire tests at muzzle velocities of 3500 ft/sec when conditioned over a temperature range of -65°F to + 160°F. Accuracy in these tests met specifications for GAU-8 target practice ammunition. However, additional single shot tests performed with samples from the final 300 projectiles delivered under the contract showed accuracy and structural integrity problems. These projectiles incorporated all design and fabrication procedure changes developed under this contract to solve these problems. As a result, the Air Force has decided to delay further development of this projectile design concept.

PREFACE

This program was conducted by DeBell & Richardson, Division of Springborn Laboratories, Inc., Water Street, Enfield, Connecticut 06082, under contract No. F08635-76-C-0195 with the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida. Lieutenant Paul A. Weber (DLDG) managed the program for the Armament Laboratory. Mr. Roy B. Steidley was the Project Manager for DeBell & Richardson. The program was conducted during the period from March 1976 to December 1976.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Gerald P. D'Arcy, Colonel, USAF
Chief, Guns, Rockets and Explosives Division

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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SECTION I

INTRODUCTION

The objective of this program was to develop a target practice projectile less expensive than the standard GAU-8 TP projectile that has minimal ricochet characteristics. The frangible projectile consists of a column of washers encapsulated in a plastic jacket; on impact, the jacket ruptures and washers scatter with reduced ricochet trajectories. A 30mm target practice projectile of conventional design can ricochet a distance of over 20,000 feet and reach a height of 7000 feet. A 20mm target practice projectile can travel a distance of 10,000 feet and reach a height of 3000 feet after target impact. The frangible round should reduce these distances by a factor of 10.

The cost and safety benefits of a frangible target practice projectile appear substantial. They include reduced aircraft losses and damage due to ricochet impacts and reduced operational costs through more efficient use of existing strafing ranges. A cost saving should also result because of the simplicity of the frangible projectile design when compared to that of the machined steel and aluminum GAU-8 target practice projectile.

During the past 10 years, there have been 271 documented cases in the USAF where projectiles have struck the firing aircraft during routine practice strafing missions, over 50 percent of which involved the F-4. Two of these incidents resulted in loss of life and aircraft. During the past 3.5 years, 1.3 million dollars have been spent for aircraft parts to repair damage caused by ricochets, not including losses caused by damaged aircraft down time or excessive maintenance workloads.

The initial work on a plastic frangible projectile was accomplished in 20mm calibers, and ricochet angles and distances were significantly reduced. Similar reductions are expected as a result of the 30mm program. Premature projectile breakup during gun launch was the major problem throughout the 20mm program and continued to be a problem during the initial 30mm work. A projectile design with a steel tube through the column of circular washers was finally tested and found to satisfy the criterion of 100 percent structural integrity during launch and flight. This design structure was demonstrated to remain intact until impact when fired at a muzzle velocity of 3500 ft/sec over a temperature range of -65° to 160°F. The final performance area requiring further development is projectile dispersion. A metal bore-rider ring was tested experimentally on a few rounds during the previous work and showed excellent promise as the solution to the dispersion problem.

This program covers final design modifications to the 30mm frangible target practice projectile configuration generated under contract F08635-74-C-0087 and reported in Reference 1, testing by the contractor, and fabrication and delivery of a quantity of frangible projectiles.

SECTION II

TECHNICAL DISCUSSION

The technical effort discussed herein for the development of a successful 30mm plastic frangible projectile includes establishment of design parameters, design evolution, and a final design capable of meeting all requirements.

DESIGN PARAMETERS

The basic design of the projectile was established as a result of the work completed by the Contractor in contract F08635-74-C-0087 and as reported in Reference 1. The requirements for the improved projectiles developed under this contract were virtually the same as the previous, except that additional requirements were imposed. These additional requirements included the following:

1) The accuracy shall be improved such that it would meet the Prime Item Specification (see Reference 2) requirement for a dispersion standard deviation about the mean impact point to be equal to or less than 0.7 milliradian. This could be accomplished through the use of a forward steel bore-riding ring, such as that tested in the previous contract, or by any suitable means.

2) The plastic material used for the outer shell would not be limited to the glass reinforced nylon 12 used in the previous contract in order to permit the use of domestically available materials for such applications.

3) The ballistic characteristics of the projectile shall not be altered by ablation or aerodynamic heating, abrasions, or deformation, either within the gun or in flight.

4) The performance shall not be altered by exposure to a chambered condition with a barrel temperature of 1350°F for a period of 0.25 second.

5) Experimentation shall be performed with colorants of a nature that would result in finished projectiles having the standard blue color for target practice ammunition. However, the colorants were not to affect the performance of the projectiles.

FINAL PROJECTILE DESIGN

Figure 1 shows the final configuration of the 30mm plastic frangible projectile which was accepted at the end of the contract. It consisted of a 30 percent glass reinforced nylon 12 skin, 50 zinc phosphated punched steel washers in 4 sizes, a steel center tube, a zinc phosphated steel end cap, a steel bore-rider ring, and a 50 percent glass reinforced nylon 12 nose/filler piece.

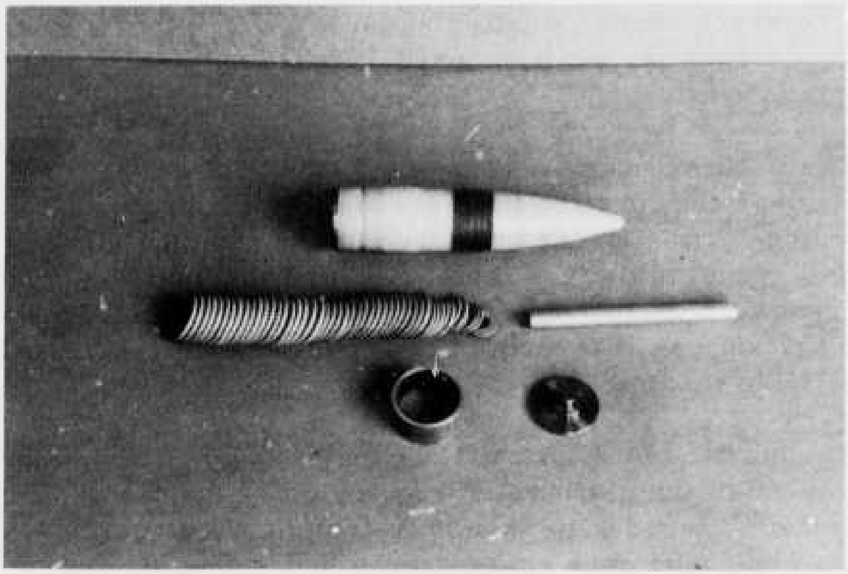


Figure 1. 30mm Plastic Frangible Projectile Final Configuration

Huls L1801 nylon 12 was selected for its toughness, malleability, and proven performance, and long glass fiber was used as the reinforcement. Thirty percent glass reinforcement was selected for the skin to provide a combination of properties necessary to achieve spin-up while resisting fracture, and 50 percent glass reinforcement was selected for the nose primarily because of low shrinkage. The compounds were produced by Thermofil, their product identifications N9-3000FG and N9-5000FG, respectively.

Washer sizes were selected consistent with the developed skin stress profile. The ID and OD tolerances were maintained at ±0.003 inch, and the concentricity was specified at 0.005 inch TIR. These tolerances were necessary to maintain dynamic balance within the projectile. The washers, when stacked, were dipped in M&T 253-P primer and baked while mandreled to form a solid insert for molding.

The washer stack was preheated prior to molding and placed on a centering core within a mold. The skin was then molded over the stack for full encapsulation. After cooling and crystallization of the plastic skin over the stack, the center tube was inserted. The subassembly was placed in a second mold for injecting the nose and filler. The steel end cap, primed and baked in the same manner as the washer stack, was inserted and induction bonded to the rear of the semi-finished projectile. The washers were then induction bonded to the skin. A seat was machined into the outer skin, a bore-rider ring blank was press fit to the seat, and its outer profile was machined.

The final projectile has an average weight of 355 grams (5480 grains), with its center of gravity located an average of 2.00 inches forward of the rear of the end cap. It measured 5.53 inches overall, and had polar and transverse moments of inertia of 0.097 and 1.24 lb-in^2, respectively. When loaded into standard GAU-8/A cartridge cases with 144 grams of CIL 3331 propellant and fired from a GAU-8/A phase II constant twist Mann barrel, the 30mm plastic frangible projectile remained intact at an average muzzle velocity of approximately 3450 ft/sec with an average chamber pressure of approximately 55,000 psi. The standard deviation of dispersion about the mean impact point was less than 0.7 milliradian.

DESIGN EVOLUTION

The projectile which had been developed under the previous contract utilized 30 percent fiberglass reinforced nylon 12 plastic in the outer skin. From laser photographs of those projectiles in flight it was found that deep engraving was evident at the intersection of the bourrelet and the ogive, suggesting that the skin softness was contributory towards excessive in-bore balloting and subsequent high muzzle exit yaw and resultant inaccuracy. The use of a steel bore-rider ring had been demonstrated in the previous contract to be the corrective action for this problem. However, it was considered to be expensive.

As an alternate, methods of increasing the hardness of the skin were sought. In a concurrent program with the Air Force Materials Laboratory (see Reference 3) the Contractor had established procedures for utilizing nylon 612, a commercially available domestic material, for 20mm projectile rotating bands. Nylon 612, especially when glass reinforced, is a harder material than nylon 12 at similar reinforcement levels, and attempts to utilize it in the frangible projectile activity were programmed. In addition, it was felt that nylon 12 could be made more resistant to undesirable forward engraving by increasing its glass content from 30 percent, but that the increase in glass content might render the material too brittle for use in the projectile rotating band area. This was also considered for high glass loadings in nylon 612. It was therefore conceived that the highly glass loaded plastic skins could have affixed thereto unfilled compatible plastic rotating bands.

However, to utilize this concept it was necessary to develop a method for bonding between the unfilled rotating band material and the glass reinforced plastic skin. In the laboratory, 1-inch diameter molded bars of skin materials were prepared in experimental processing to receive collars of unfilled plastic materials which could be used as rotating bands for the projectiles. After preparation, 0.375-inch long by 0.125-inch thick collars of the materials were injection molded directly onto the bars of glass reinforced skin materials. The intent was to develop an in-mold secondarily processable bond. The bars with their collars were placed in a test fixture such that the 1-inch bars were guided in a central hole of a flat plate, and that one of the flat faces of the collar was resting on the surface of the plate. Using a compression test machine the bar was pushed from the collar, and the shear strength of the bonded joint was recorded. The materials, adhesives, and processes employed to achieve a bond are listed in Table 1. From the results of testing it was determined that flame treating the fiber glass reinforced nylon outer skin before molding to it an unfilled compatible material would yield a bond shear strength sufficient to resist the torque of spin-up of the projectile in the barrel.

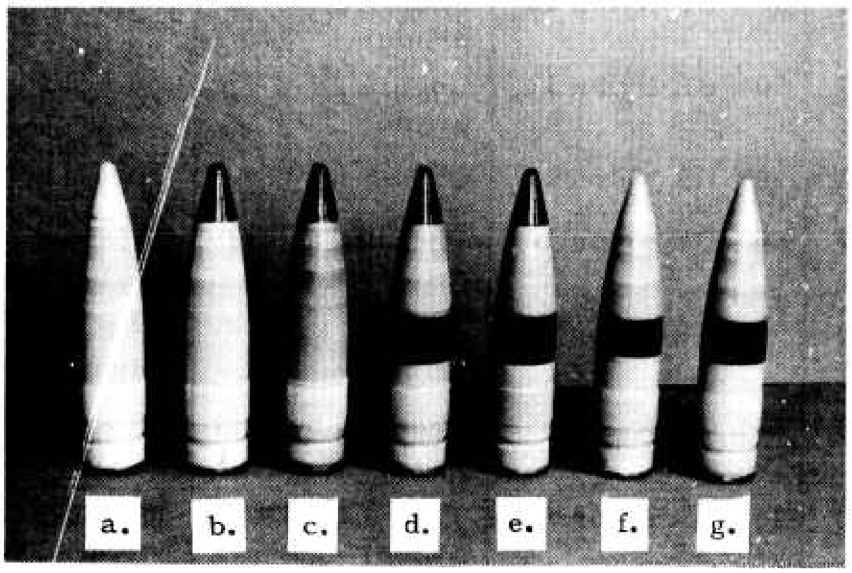
Another design consideration early in the program was the resistance of the projectile to the effects of aerodynamic heat, or ablation. Surplus projectiles from the previous development activity (contract F08635-74-C-0087) were screened in a 5 megawatt PWT Arc Heater Test Unit to determine their ablation characteristics. The units were subjected to effluent gas (air) from a Mach 3.2 nozzle, with a stagnation pressure and hot wall stagnation point heat transfer rate of 14.2 atmospheres and 760 Btu/ft^2-sec, respectively. The testing was performed at the Propulsion Wind Tunnel Facility, Arnold Engineering Development Center, Arnold Air Force Station, Tennessee, and the results were reported in Reference 4. The testing showed that the projectile length foreshortened by up to 0.250 inch, and its weight decreased up to 5.647 grams as a result of the effects of the ablation. Because of this the projectile nose material, 50 percent glass reinforced nylon 12, was considered for change to a known ablation resistant material. Fiberite FM5064 glass reinforced phenolic, a compression moldable material, was selected for the projectile nose. Molded noses would be adhesively bonded to the projectile outer skin moldings.

TABLE 1. BOND STRENGTH OF ROTATION BAND MATERIALS TO OUTER SHELL MATERIALS

Specimen Ident. No.	Shell Material	Surface Preparation	Band Material	Joint Shear psi
116785-100	50% GR Nylon 12	MEK wash	Nylon 12	340
116785-101	43% GR Nylon 612	MEK wash	Nylon 12	310
116785-102	50% GR Nylon 12	MEK wash	TP ester polyurethane	290
116785-103	43% GR Nylon 612	MEK wash	TP ester polyurethane	300
116786-104	50% GR Nylon 12	Phenolic butyral primer	Nylon 12	200
116786-105	50% GR Nylon 12	Loctite L4-4 primer	Nylon 12	240
116786-106	50% GR Nylon 12	Ozonated	Nylon 12	110
116786-107	50% GR Nylon 12	Phenolic butyral primer	TP ester polyurethane	420
116786-108	50% GR Nylon 12	Thixon 1153 primer	TP ester polyurethane	370
116786-109	43% GR Nylon 612	Phenolic butyral primer	TP ester polyurethane	240
116786-110	43% GR Nylon 612	Thixon 1153 primer	TP ester polyurethane	310
116786-111	43% GR Nylon 612	Phenolic butyral primer	Nylon 612	280
116786-112	43% GR Nylon 612	Loctite L4-34 primer	Nylon 612	640
116786-113	43% GR Nylon 612	Ozonated	Nylon 612	300
116787-114	50% GR Nylon 12	Flame treated	Nylon 12	3440
116787-115	50% GR Nylon 12	Phenol solvent	Nylon 12	3220
116787-116	43% GR Nylon 12	Flame treated	Nylon 612	3800
116787-117	43% GR Nylon 612	Phenol solvent	Nylon 612	3290

A third consideration, one that was process oriented, was the sequence by which the steel stiffening center tube was assembled to the washer stack. In the previous activity the tube was inserted into the washer stack after molding of the outer skin. The primed washer stacks, prior to molding the outer skin, however, were delicate, and often they would break apart due to handling in the molding operation. It was felt that the washers could be stacked directly onto the center tubes and primed, and the resulting sub-assembly would be sufficiently rugged to resist breakage during handling.

With these considerations development activity for the projectiles was initiated. A summary of the materials used and their constructions are presented in Table 2, and the results of firing tests performed for each configuration are presented in Table 3. Figure 2 chronologizes the design evolution, and the details of each configuration are presented herein.



a. Previously Developed Unit
b. R&D Series 116791-118
c. R&D Series 116792-120
d. R&D Series 116794-124
e. R&D Series 116797-127
f. R&D Series 120876-128
g. Final Design EG-B85-D

Figure 2. Projectile Design Evolution

TABLE 2. DESCRIPTION AND IDENTIFICATION OF DEVELOPMENT PROJECTILES

Projectile Series No.	Configuration No.	Shell Material	Rotation Band	Bore Rider	Nose Material	Bonding Method			Average Weight (grains)
						Tail	Nose	Washer Stack	
116791-118	EG-B64-D	30% GR Nylon 12	Integral with shell	None	GR Phenolic	(A)	(A)	(I)	5650
116791-119	EG-B64-D	33% GR Nylon 612	Integral with shell	None	GR Phenolic	(A)	(A)	(I)	5670
116792-120	EG-B67-D	50% GR Nylon 12	Nylon 12, secondary	None	GR Phenolic	(A)	(A)	(I)	5715
116792-121	EG-B67-D	43% GR Nylon 612	Nylon 612, secondary	None	GR Phenolic	(A)	(A)	(I)	5710
116793-122	EG-B69-D	50% GR Nylon 12	Nylon 12, secondary	None	GR Phenolic	(A)	(A)	(I)	5595
116793-123	EG-B69-D	43% GR Nylon 612	Nylon 612, secondary	None	GR Phenolic	(A)	(A)	(I)	5585
116794-124	EG-B81-D	30% GR Nylon 12	Integral with shell	Steel Ring	GR Phenolic	(A)	(A)	(I)	5765
116794-125	EG-B81-D	33% GR Nylon 612	Integral with shell	Steel Ring	GR Phenolic	(A)	(A)	(I)	5775
116797-126	EG-B81-D	30% GR Nylon 12	Integral with shell	Steel Ring	GR Phenolic	(I)	(A)	(I)	5730
116797-127	EG-B81-D	30% GR Nylon 12, blue pigmented							
120876-128	EG-B83-D	30% GR Nylon 12	Integral with shell	Steel Ring	50% GR Nylon 12	(I)	(M)	(I)	5650
120876-129	EG-B84-D	30% GR Nylon 12	Integral with shell	Maltese Cross	50% GR Nylon 12	(I)	(M)	(O)	5620
120881-130	EG-B85-D	25% GR Nylon 612	Integral with shell	Steel Ring	43% GR Nylon 612	(I)	(M)	(I)	5480
120881-131	EG-B85-D	30% GR Nylon 12	Integral with shell	Steel Ring	50% GR Nylon 12	(I)	(M)	(I)	5480

Bonding Methods Legend: (A): Oven cured epoxy adhesive (M): In-mold contact bonded
(I): Induction bonded (O): Oven bonded

TABLE 3. RESULTS OF FIRING TRIALS ON DEVELOPMENT PROJECTILES

Projectile Series No.	Test Temperature (°F)	No. of Units	Chamber Pressure (kpsi)			Muzzle Velocity (ft/sec)		Dispersion (milliradians)	Max. Yaw at 2000 inches (degrees)	Remarks
			Mean	Std. Dev.	Mean + 3 × Std. Dev.	Average	Std. Dev.			
116791-118	Amb.	1	--	--	--	--	--	--	--	Hot propellant; unit broke up
	-65	5	58.0	2.2	64.6	3516 (1 unit)	--	--	9	Three units broke up, others intact
	160	1	--	--	--	3543	--	--	10	Intact
116791-119	Amb.	1	60.0	--	--	--	--	--	--	Tail discarded
	160	1	48.0	--	--	3478	--	--	--	Broke up
116792-120	Amb.	1	--	--	--	--	--	--	14	Intact
	-65	5	52.4	0.8	54.8	3505	13	3.10	15	One band discard, one tail discard, others satisfactory
	160	1	54.0	--	--	3546	--	--	--	Intact
116792-121	Amb.	1	62.0	--	--	--	--	--	--	Broke up
116793-122	Amb.	1	--	--	--	--	--	--	(True)	Intact
	160	1	52.0	--	--	3561	--	--	--	Broke up
116793-123	Amb.	1	62.0	--	--	--	--	--	10	Intact
116794-124	Amb.	1	--	--	--	--	--	--	(Slight)	
	-65	5	55.2	5.2	70.8	--	--	2.69	(True)	One unit discarded tail, others intact
	160	2	54.0	--	--	3081 (1 unit)	--	--	--	One unit discarded tail and center tube, other unit intact
116794-125	Amb.	1	56.0	--	--	--	--	--	--	Intact
116797-126	-65	9	47.5	2.7	55.6	3352	35	1.34	4	
	160	10	64.1	2.0	70.1	3527	19	1.02	4	Four units broke up, others intact
116797-127	-65	2	55.0	--	--	3417	--	--	--	Massive break up (tiny fragments recovered from firing range)
	160	2	65.5	--	--	3533	--	--	--	
120876-128	-65	4	53.3	--	--	3243	--	--	4	One unit broke up, others intact
	160	5	58.3	1.1	61.6	3391	74	1.05	(True)	One unit either very inaccurate (hit yaw stand) or broke up downrange. Others intact and satisfactory
120876-129	Amb.	1	62.0	--	--	--	--	--	--	Massive break up

EG-B64-D Configuration; R & D Series 116791-118 and 116791-119

This configuration was basically the same as that which had been qualified in the previous development activity, except that the nose was compression molded fiber glass reinforced phenolic resin, and the nose and end cap were adhesive bonded to the structure. In addition, the sequence at which the center tube was assembled was changed to accommodate processing, and 30 percent fiber glass reinforced nylon 12 (baseline material; R & D Series 116791-118) was compared with the harder 33 percent fiber glass reinforced nylon 612 (R & D Series 116791-119) for the outer skin. The rotating bands were integral with the outer skin. The configuration is shown in Figure 3.

In these series the steel center tube was positioned on the stacking mandrels, and the washers were assembled over the tube, a departure from the previous activity where the center tube was fit within the ID of the washers after the outer skin was molded. The washers were coated with M&T 253-P primer and baked, and the assembled washer stacks were molded with the outer skin materials. The steel end caps were primed with M&T 253-P primer and baked, and they were bonded to the rear of the projectile with an epoxy adhesive. The ID of the center tubes was press fit with G-10 fiber glass reinforced epoxy rod stock in order to fill the void, and the compression molded fiber glass reinforced phenolic nose pieces were bonded to the forward end of the outer skin with an epoxy adhesive.

The projectiles were test fired by the sponsor at the BEF facility at Eglin Air Force Base in order to determine their structural integrity and to obtain preliminary accuracy data. The units were loaded with 150 grams of CIL 3352 propellant into standard GAU-8/A aluminum cartridge cases. The ammunition was temperature conditioned at ambient, -65°F, and 160°F before firing from a standard GAU-8/A Phase II Mann barrel. The units exhibited breakup, end cap discard, and large yaw, but generally the nylon 12 projectiles performed better than the nylon 612 units. However, the high yaw value suggested that neither material was sufficiently hard to resist bourrelet engraving during balloting.

EG-B67-D Configuration; R & D Series 116792-120 and 116792-121

This configuration utilized outer skins of very high fiber glass loadings, and secondarily bonded unfilled plastic rotating bands were employed. Fifty percent glass reinforced nylon 12 was used in the outer skin, in conjunction with unfilled nylon 12 as a rotating band, for R & D Series 116792-120, and 43 percent glass filled nylon 612 was used for the outer skin, in conjunction with unfilled nylon 612 as a rotating band, for R & D Series 116792-121. The configuration is shown in Figure 4.

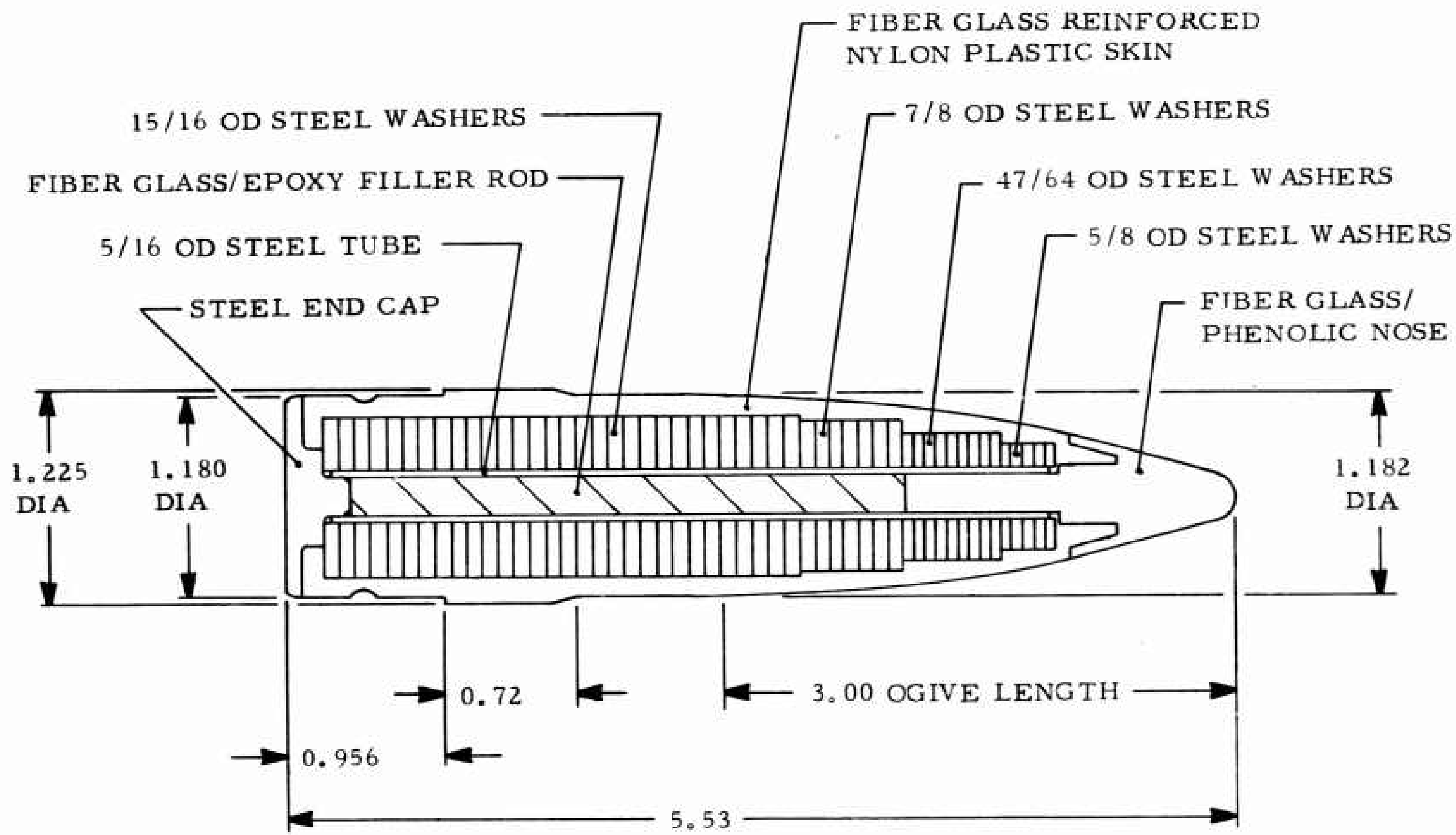


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Figure 3. EG-B64-D Projectile Configuration

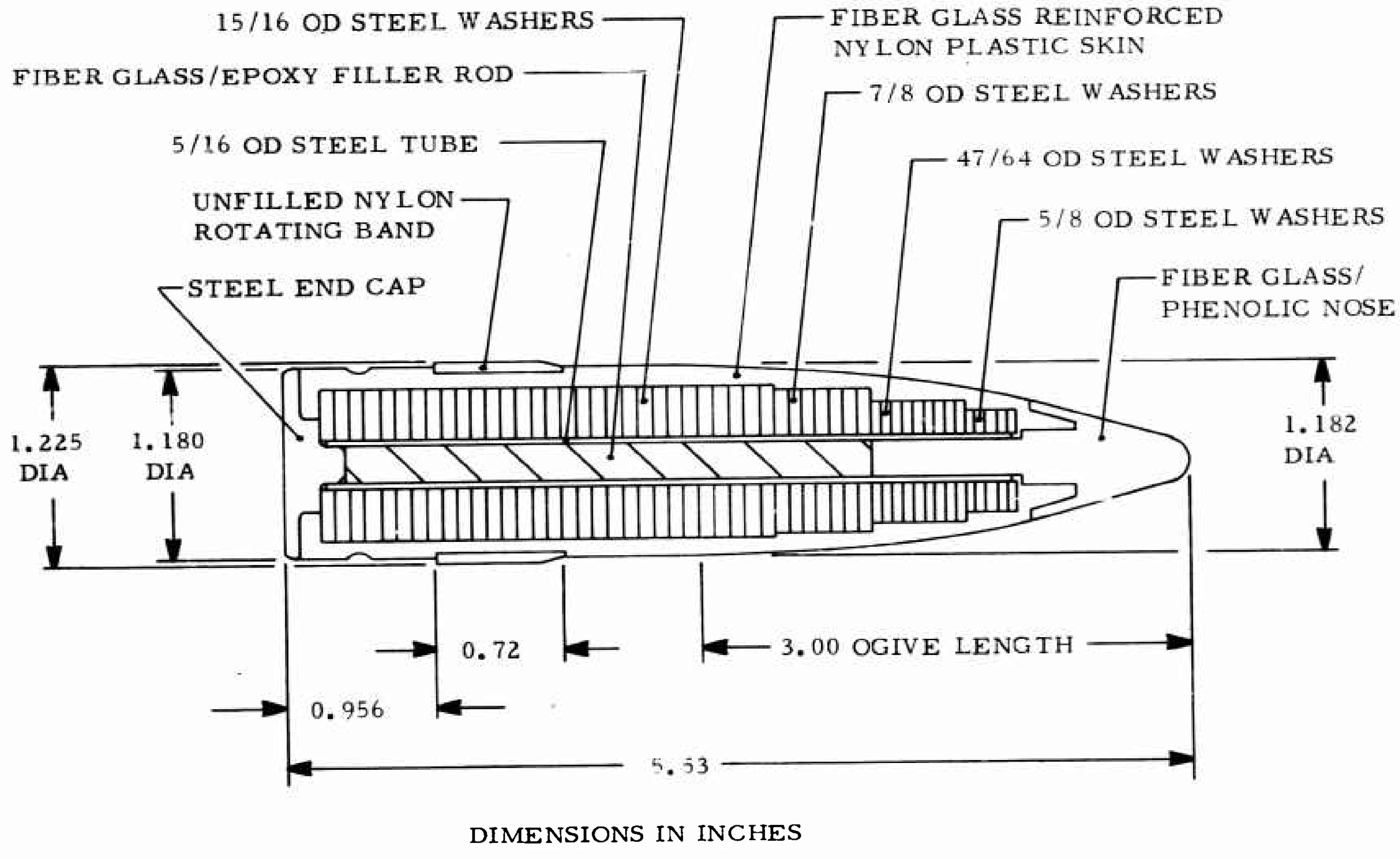


Figure 4. EG-B67-D Projectile Configuration

In these series the steel center tube was positioned on the stacking mandrels, and the washers were assembled over the tube, this method being the same as used in the EG-B64-D configuration projectiles. The washers were coated with M&T 253-P primer and baked, and the assembled washer stacks were molded with the outer skin materials. A band seat was machined into the outer skin to accept a rotating band, and the unfilled plastic band was molded thereto after flame treatment to render the seat receptive to an in-mold bond. The steel end caps were coated with M&T 253-P primer and baked, and they were bonded to the rear of the projectile with an epoxy adhesive. The ID of the center tubes were press fit with G-10 fiber glass reinforced epoxy rod stock in order to fill the ID void, and the compression molded fiber glass reinforced phenolic noses were bonded to the forward end of the projectile with an epoxy adhesive.

The projectiles were test fired by the sponsor at the BEF facility in order to determine their structural integrity and to obtain preliminary accuracy data. The units were loaded with 150 grams of CIL 3352 propellant into standard GAU-8/A aluminum cartridge cases. The ammunition was conditioned at ambient, -65°F, and 160°F before firing from a standard GAU-8/A Phase II Mann barrel. The units composed of nylon 12 materials basically remained intact, except that at -65°F one rotating band and one end cap discarded. The accuracy, however, at -65°F was 3.10 milliradians (standard deviation of impact points about the mean impact point; Aberdeen Ballistics Research Laboratory method - Reference 5), and a maximum yaw of 15 degrees was observed from signature cards. The one unit composed of nylon 612 materials broke up at ambient firing conditions, and no further units were tested. The testing suggested that the particular grade of nylon 612 (Zytel 77G43L) was unsatisfactory for this application, and that the concept of the secondarily affixed unfilled rotating band was marginal. The inaccuracy obtained with projectiles composed of 50 percent fiber glass reinforced nylon 12 suggested that the hardness increase afforded by the higher glass loading was insufficient to resist bourrelet engraving during balloting.

EG-B69-D Configuration: R & D Series 116793-122 and 116793-123

This configuration was virtually identical to the EG-B67-D configuration, except that a seat, or relief, was provided in the washer stack under the rotating band. Series 116792-122 used a 50 percent fiber glass reinforced nylon 12 outer skin with an unfilled nylon 12 rotating band, and series 116792-123 used a 43 percent nylon 612 outer skin and an unfilled nylon 612 rotating band. The configuration is shown in Figure 5, and the processing details were the same as those described for the EG-B67-B units above.

The projectiles were test fired by the sponsor at the BEF facility in order to determine their structural integrity and to obtain preliminary accuracy

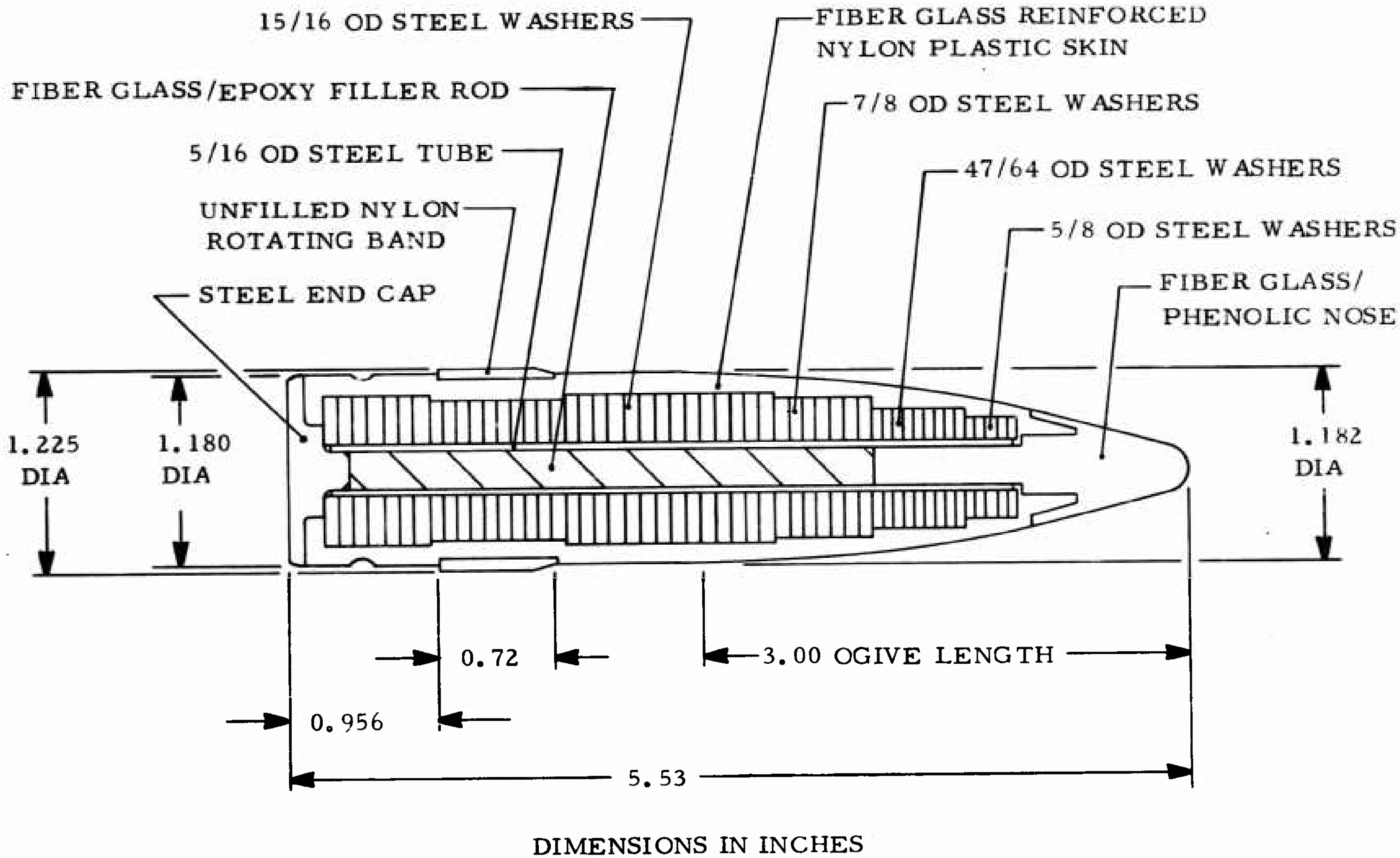


Figure 5. EG-B69-D Projectile Configuration

data. The units were loaded with 150 grams of CIL 3352 propellant into standard GAU-8/A aluminum cartridge cases. The ammunition was conditioned at ambient, -65°F, and 160°F before firing from a standard GAU-8/A Phase II Mann barrel. Only one unit composed of nylon 12 materials was test fired, and it broke up at ambient conditions. One unit composed of nylon 612 materials remained intact and true at ambient conditions, but one other unit fired at 160°F broke up. These firings, performed concurrently with those of configuration EG-B67-D, provided sufficient evidence to eliminate concepts having a secondarily attached unfilled plastic rotating band. It was apparent that breakups may have been caused either by the processing used to mold the band or by the effects of the band seat to the outer skin structure.

EG-B81-D Configuration; R & D Series 116794-124 and 116794-125

This configuration was virtually the same as the EG-B64-D configuration described above, except that a steel bore riding ring was employed at the junction of the bourrelet and the ogive. The rotating band was integral with the skin, 30 percent fiber glass reinforced nylon 12 was the skin material for the 116794-124 series, and 33 percent fiber glass reinforced nylon 612 was used for the 116794-125 series. The configuration is shown in Figure 6.

In these series the steel center tube was positioned on the stacking mandrels, and the washers were assembled over the tube, primed with M&T 253-P primer, and baked. The outer skin was molded over the assembled washer stack, after which a seat was machined into the skin to accept the bore rider ring. The ring was press fit to the seat, and its exterior was machined to conform to the projectile bourrelet and ogive. The steel end caps were coated with M&T 253-P primer and baked, and they were bonded to the rear of the projectile with an epoxy adhesive. The ID of the center tubes were press fit with G-10 fiber glass reinforced epoxy rod stock to fill the void, and the compression molded fiber glass reinforced phenolic nose pieces were bonded to the forward end of the projectiles with an epoxy adhesive.

The projectiles were test fired by the sponsor at the BEF facility. The units were loaded with 150 grams of CIL 3352 propellant into standard GAU-8/A aluminum cartridge cases. The ammunition was conditioned at ambient, -65°F, and 160°F before firing from a standard GAU-8/A Phase II Mann barrel. In this testing, the washer and skin structure of the nylon 12 units remained intact, but in two cases the end caps discarded. Dispersion improved, but still exceed requirements. However, the inaccuracy may have been caused by other circumstances.

One unit only of the nylon 612 material was fired, and the results were satisfactory. The testing illustrated that the steel bore rider ring concept was

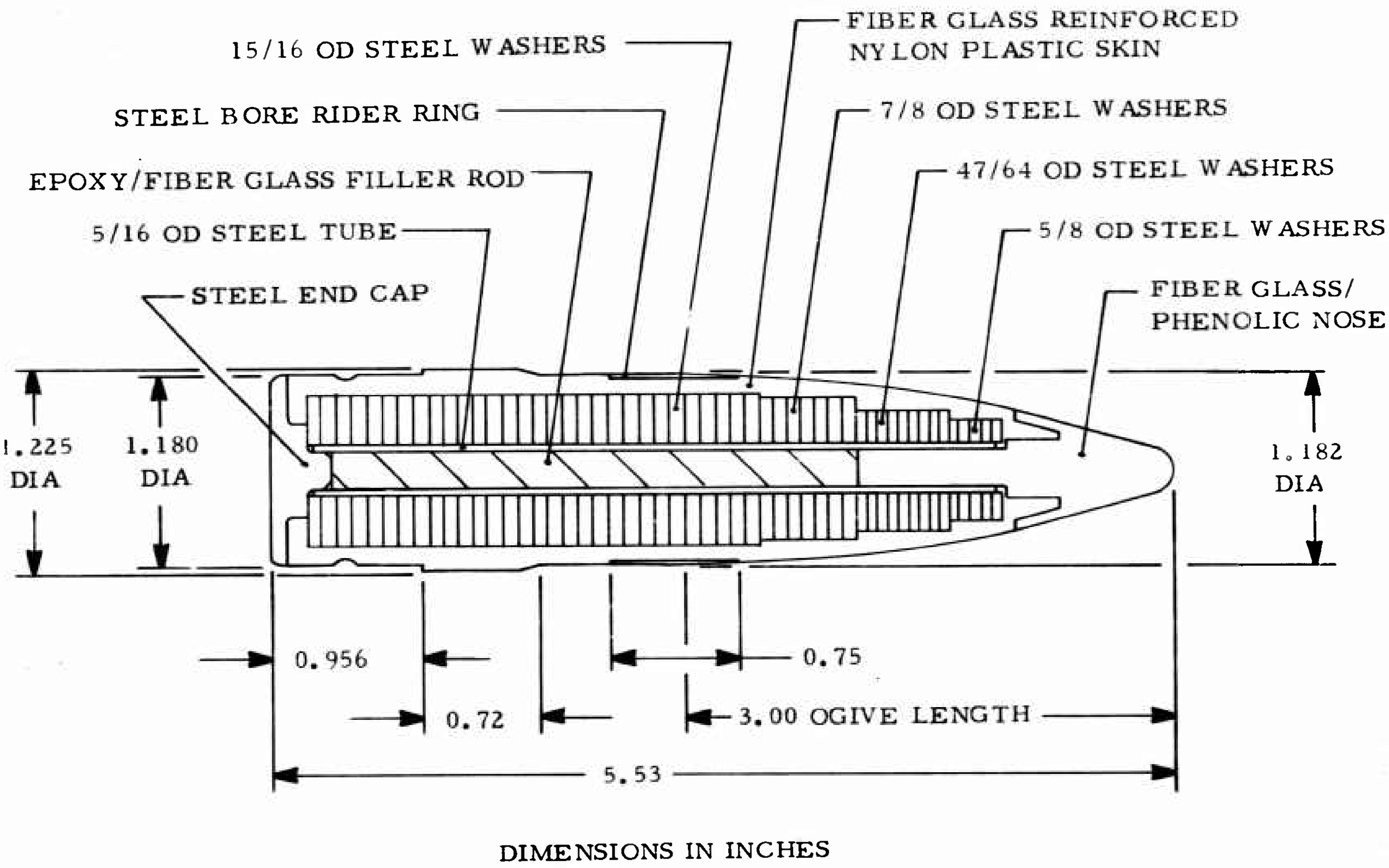


Figure 6. EG-B81-D Projectile Configuration

superior to the other considerations for accuracy improvement, and it also showed that the adhesive bond for the tail piece was unsatisfactory to resist the gun environment.

EG-B81-D Configuration; R & D Series 116797-126 and 116797-127

Based on the results of the firing trials of R&D series 116794-124 process modifications were made to improve the tail bond for the same configuration. In R&D series 116797-126 and 116797-127 the tail bond was consummated by induction heating methods identical to those used in the previous contract. The remainder of the processing was identical to those used in R&D series 116794-124. Thirty percent fiber glass reinforced nylon 12 was used for series 116797-126, and a blue pigmented version thereof was used for series 116797-127. Pigmenting of the plastic outer skin was selected to provide TP ammunition color matching without adding manufacturing operations to achieve proper coloring.

The projectiles were test fired by the sponsor at the BEF facility in order to obtain accuracy data and to determine the effects of the blue pigment on the structural integrity of the projectiles. The units were loaded with 144 grams of CIL 3331 propellant into standard aluminum GAU-8/A cartridge cases. The ammunition was conditioned at ambient, -65°F, and 160°F before firing from a standard GAU-8/A Phase II Mann barrel.

The significant finding of this test series was that the particular colorant was deleterious to projectile performance. All colored projectiles broke up on firing, whereas the uncolored counterpart, for the most part, remained intact. Recovered fragments of the colored projectiles were very small and showed brittle fracture lines.

Moreover, the accuracy of the 116797-126 (uncolored) rounds exceeded the prime item specification requirement of a standard deviation of impact points about the mean point of 0.7 milliradian. However, the standard AOMC steel TP projectiles used for instrumentation check-out had an accuracy of 1.08 milliradians and suggested that some looseness might exist in the gun mounting system, as these TP's normally are well within the specified value.

No uncolored (116797-126) frangible projectiles broke up at -65°F, where low temperature brittleness would be most pronounced. However, 4 of 10 units broke up at 160°F. Prior to testing, the projectiles were temperature conditioned while inserted within the loaded cartridge case. At 160°F the resulting chamber pressures were quite high, resulting in a mean pressure of 64.1 kpsi, a standard deviation of 2.0 kpsi, and a mean plus 3 standard deviation of 70.1 kpsi. The latter exceeded the prime item specification requirement of 66.6 kpsi and suggests an overtest condition.

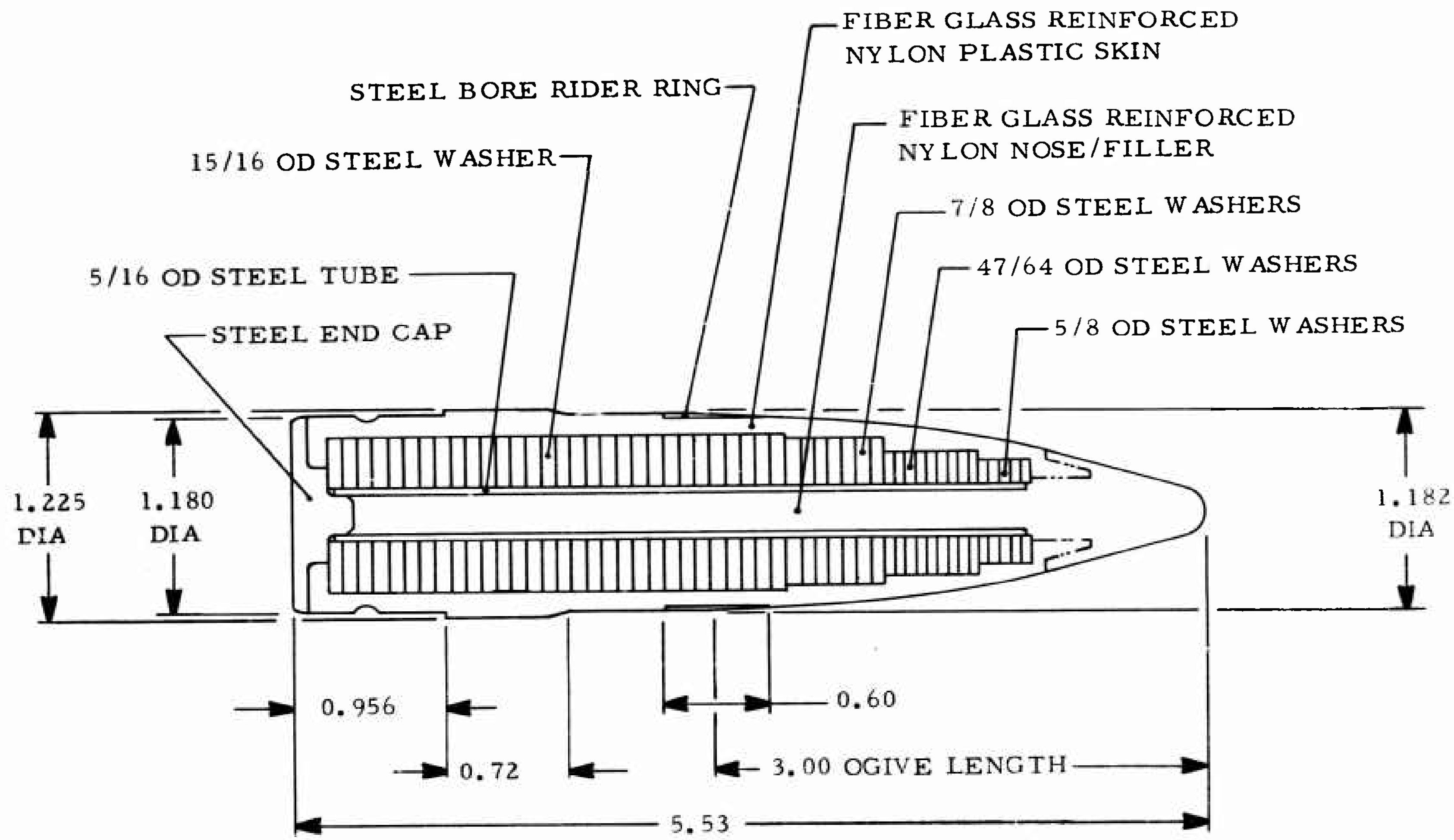
A dynamic analysis of the projectile outer skin was performed for the 116797-126 projectiles and it showed that the response shear level in the skin at the aft edge of the bore rider ring to be 5410 psi, a level higher than the limiting value of 4920 psi responsive shear stress level just forward of the rotation band. This suggested that the rear edge of the bore-rider ring should be moved forward such that the resulting stress level at the rear edge of the ring seat would be less than that of the forward edge of the rotation band, since that particular stress level had been demonstrated previously to be satisfactory under gunfire conditions within the requirements of the prime item specification. Configuration EG-B83-D reflects this change, with a movement of the bore rider ring 0.188 inch forward from where it existed on the EG-B81-D configuration. The EG-B83-D configuration is shown in Figure 7.

Further analysis showed that the secondarily bonded glass reinforced phenolic nose had a tendency to be angularly eccentric from the rest of the projectile. This type of nose was established for ablation resistance purposes and it was a departure from the molded-through-the-projectile nose used on previously qualified units. Aerodynamic analyses performed by Eglin on units having the original type of nose which had been subjected to ablation testing at Arnold Engineering Development Center (Reference 4) showed that, although approximately 0.25 inch of nose ablated during testing, negligible effects on aerodynamic performance would be expected. Consequently it was decided to return to the original style of nose piece, one that remains aligned with the projectile body.

EG-B83-D Configuration; R & D Series 120876-128

Based on the results of firing trials on the EG-B81-D configuration projectiles and the evaluation of the aerodynamic effects to the projectiles as a result of nose ablation, configuration EG-B83-D was developed, and it is as shown in Figure 7. In this design the bore-rider ring was shortened approximately 0.188 inch from the previous configuration, and the fiber glass reinforced phenolic nose was replaced with 50 percent fiber glass reinforced nylon 12 which could be injection molded directly through the center tube ID to fill the void and form the nose. This latter consideration was identical to that employed in projectiles which had been qualified in the previous contract.

In R&D series 120876-128 the steel center tube was positioned on the stacking mandrels, and the washers were assembled over the tube. The washers were coated with M&T 253-P primer and baked, and the assembled washer stack was molded with the 30 percent fiber glass reinforced nylon 12 skin. Using 50 percent fiber glass reinforced nylon 12, the nose and filler were molded through the tube ID. The end caps were coated with M&T 253-P primer, baked, and induction bonded to the rear of the projectile, and the



DIMENSIONS IN INCHES

Figure 7. EG-B83-D Projectile Configuration

washer stacks were induction bonded to the outer skin. A seat was machined into the outer shell to accept the bore-rider ring, the ring was press fit onto the seat, and the exterior of the ring was machined to conform to the bourrelet and ogive.

The units were test fired by the sponsor at the BEF facility. They were loaded with CIL 3331 propellant into standard GAU-8/A aluminum cartridge cases. For ammunition conditioned at -65°F, 144 grams of propellant were used, and 141 grams were used for ammunition conditioned at 160°F. Firing trials were performed using a standard GAU-8/A Phase II Mann barrel, and flash x-ray photography was used to verify structural integrity.

One of the four 120876-128 rounds fired at -65°F broke up, while one of the six rounds fired at 160°F either broke up downrange or was so inaccurate that it hit the side of the yaw card station positioned 2000 inches downrange. No accuracy determination was made for the rounds at -65°F, as the impact points on the signature card were obviously wide spread. The accuracy of the rounds at 160°F, discounting the unit which broke up, exceeded the Prime Item Specification requirement (Reference 2).

An analysis of the failures was made. The flash x-ray photographs showed, that when a projectile broke up, the breakage occurred just forward of the aft edge of the steel bore-rider ring. Recovered fragments of failed projectiles, verified this photographic evidence, and they further indicated that such failures were independent of the length of the ring or its position on the bourrelet. Figure 8 illustrates this finding.

Whether the bore-rider rings were long, as was the case with the EG-B81-D configuration projectiles, or short, as the case was herein, or positioned more forward or rearward on the projectile, the breakage occurred just forward of the aft edge of the ring. This evidence suggested that a mass eccentricity existed in the forward section of the projectile in the overhand, or cantilevered, ogive section (with respect to interior ballistic positioning at any instant in time), which, during spin-up, could cause high bending stresses in the projectile skin.

Further investigation of the projectile components was made, and it was found that the ID of the center tube was noticeably eccentric to the OD. Since the ID surface was the register for tooling during manufacturing, and the OD surface was the register for the massive washer elements, it was logical that a mass eccentricity could exist which could result in large dynamic moments about the aft edge of the bore-riding ring. A dynamic stress analysis similar to that presented in Reference 1 was performed in which the ogive section of the projectile was idealized as a cantilevered beam with a rigid foundation at the rear of the bore-rider ring. From the analysis it was determined that a bending stress level of approximately 7700 psi could be induced into the skin at the aft edge of the ring by the

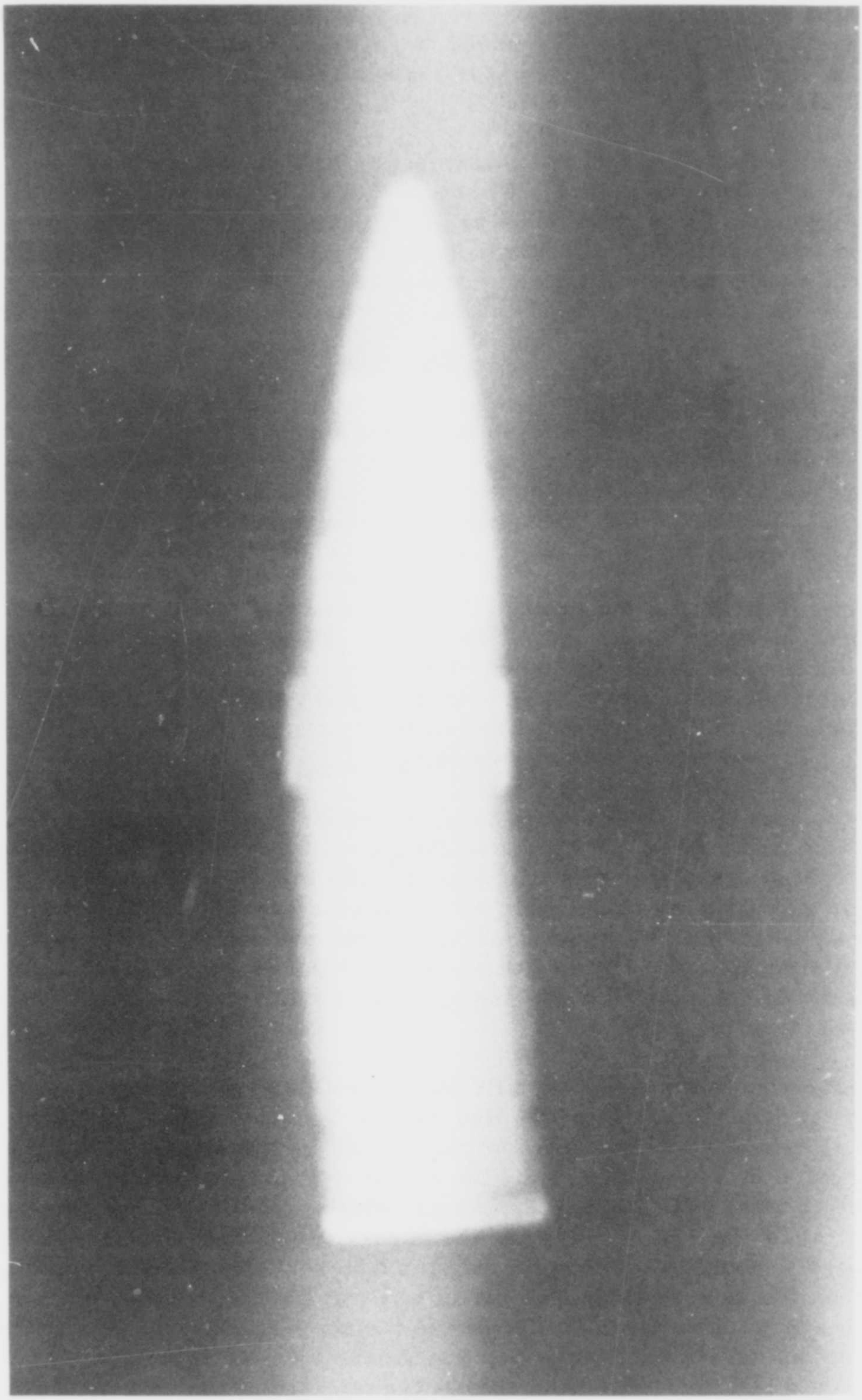


Figure 8. Flash X-Ray of 120876-128 Series Projectile at $-65^{o}F$ and 3300 Ft/Sec

dynamic moment created by a 0.010-inch mass eccentricity of the washer stack. An eccentricity of 0.010-inch was near the maximum value observed in center tube inspection. The same analysis showed that by increasing the plastic skin thickness under the bore-rider ring by reducing the OD of the adjacent washer stack from 15/16 inch to 7/8 inch, the resulting bending stress level produced by the 0.010-inch mass eccentricity would be approximately 5300 psi. The former level was considered unsafe, whereas the latter was within values used for design criteria. Based on these findings it was resolved to both reduce the washer OD under the bore-riding ring and to return to the process method used in the previous contract, in which the washers themselves were aligned to the tooling. The center tubes would be inserted to the washer stacks after molding of the outer skin, a procedure which would negate the effects of tube diameter eccentricity.

Since no configurational changes were contemplated for the aftermost portion of the projectile as a result of the analyses, it was decided to subject this configuration to debulleting tests. Using IVI manufactured aluminum cartridge cases, Aerojet Part Number 7300310-2-H, 120876-128 series projectiles were pressed into the case necks and crimped. Crimping was accomplished with a manual roller device adapted from a tube cutter, using successive passes to roll the case neck into the projectile crimp groove. After crimping, units selected at random were pressurized internally through the case primer hole with air from 10 to 100 psig and examined for leakage at the crimped interface by immersion in water. There was no evidence of leakage, and it was determined that the crimped joint provided a satisfactory environmental seal.

Debulleting tests followed, and they were accomplished by sawing off the rear of the cartridge cases, placing the crimped rounds into a fixture having chamber dimensions, and pushing the projectiles from the case neck with a follower rod at a 1 in/min debulleting rate. Debulleting was accomplished on seven units each at -65°F, 70°F, and 160°F. The debulleting loads were within the values delineated in the Prime Item Specification (Reference 2), and they are shown in Table 4.

TABLE 4. DEBULLETING LOADS FOR 30MM FRANGIBLE PROJECTILES

Test Temperature (^{o}F)	Load Range (lb)	Mean Load (lb)	Standard Deviation (lb)	Mean Load + 3 × Standard Deviation (lb)
-65	2810 - 3415	3104	215	2459
70	2725 - 2931	2931	167	2430
160	2750 - 3245	2979	213	2340
(All)	2725 - 3415	3005	201	2402

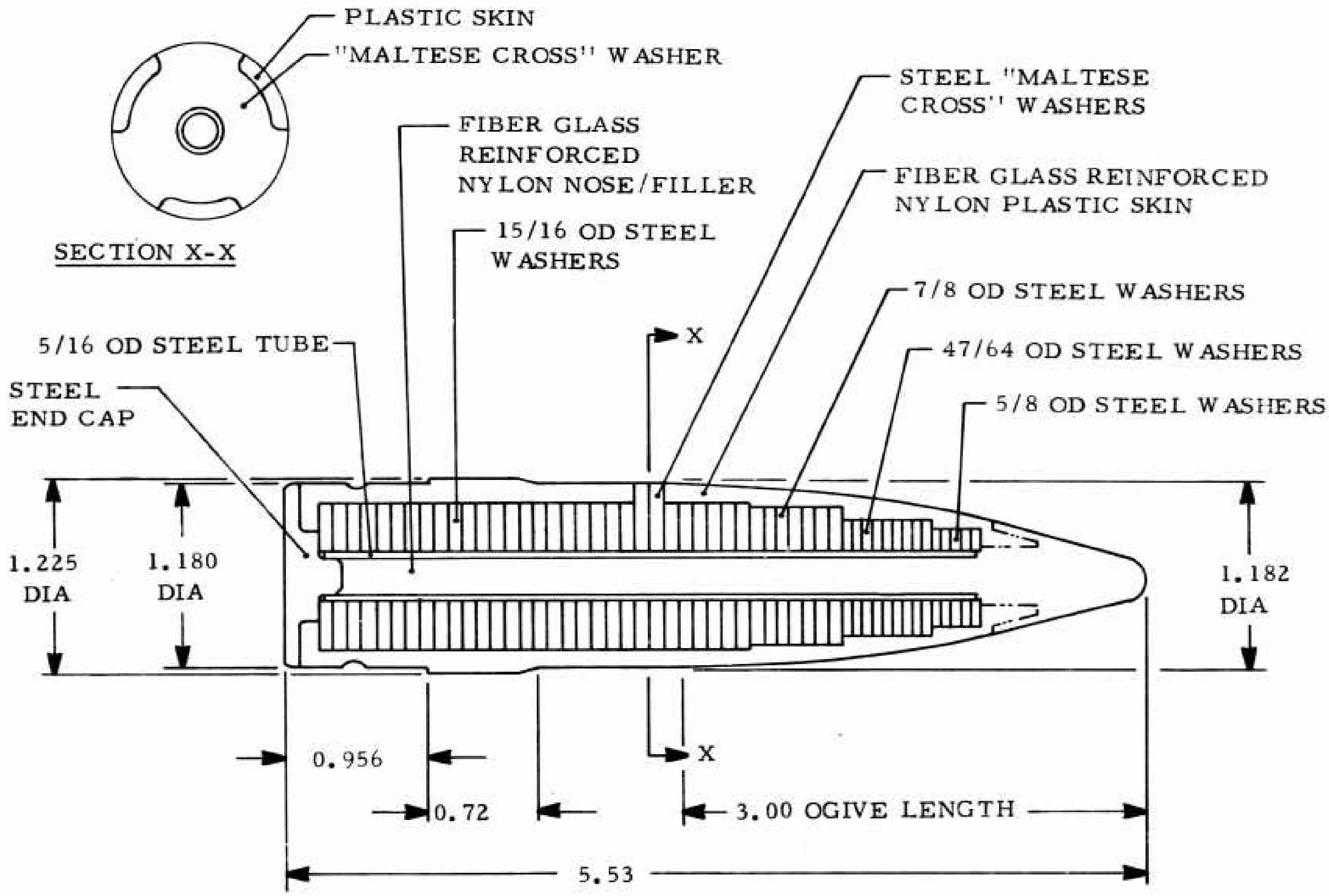
EG-B84-D Configuration; R & D Series 120876-129

In a parallel effort with the development of the EG-B83-D configuration projectiles described above, a design utilizing a bore-riding device other than a press fit and machined ring was evaluated. This concept, design configuration EG-B84-D, R&D Series 120876-129, is shown in Figure 9, and it employed two washers in the shape of a Maltese Cross. The lugs of the cross protruded through the outer skin to the bourrelet surface, and they acted as the bore riders. In this concept the steel center tube was positioned on the stacking mandrels, and the washers and machined Maltese Cross elements (with lugs aligned) were assembled over the tube. The stack was coated with M&T 253-P primer and baked, and the outer skin was injection molded thereto using 30 percent fiber glass reinforced nylon 12. The nose/filler was molded through the center tube ID using 50 percent fiber glass reinforced nylon 12. The steel end caps, primed with M&T 253-P, were induction bonded to the rear of the projectile. The protruding lugs of the cross elements precluded induction bonding since they would be local energy directors; therefore, the bond of the skin to the stack was accomplished by oven heating the projectiles in a gaseous nitrogen atmosphere.

One unit only of this series was test fired by the sponsor concurrently with the 120876-128 series projectiles. At ambient conditions the unit suffered massive breakup. The concept was abandoned.

EG-B85-D Configuration; R & D Series 120881-130

A final development lot of projectiles was prepared in which the configuration was dictated by the results of firing trials and analysis of the EG-B83-D configuration projectiles delineated above. The skin material was developed



DIMENSIONS IN INCHES

Figure 9. EG-B84-D Projectile Configuration

as a result of successful testing of domestically available materials for rotating band applications under a concurrent effort by the Contractor on contract F33615-75-C-5225 with Wright-Patterson Air Force Base. The material was DuPont's E8470-146-1 experimental 25 percent fiber glass reinforced nylon 612, and the configuration is shown in Figure 10.

In this series the washers were stacked onto the mandrels, primed with M&T 253-P primer, and baked. The assembled stacks were injection molded with the nylon 612 compound described above to form the outer skin. The steel center tube was pressed into the washer stack ID, and using commercially available DuPont Zytel 77G43L 43 percent fiber glass reinforced nylon 612, the nose/filler was molded through the tube ID. Tne remainder of the structure was as described in the EG-B83-D configuration projectiles.

Four of the units were test fired by the sponsor in the Aeroballistics Laboratory, Bay 10, using propellant, cartridge cases, and a GAU-8/A Mann barrel as previously described. Two units each were successfully fired after conditioning at ambient and at -65^{o}F. Microflash photographs of the projectiles in flight are shown in Figures 11 and 12. The success of these projectiles constructed of domestically available materials suggested that additional development work would be fruitful.

EG-B85-D Configuration; R & D Series 120881-131

The final design configuration is shown in Figure 10 and in Contractor drawing EG-B85-D appended herein. R&D Series 120881-131 of that configuration used Thermofil N9-3000 FG 30 percent fiber glass reinforced nylon 12 in the outer skin and Thermofil N9-5000 FG 50 percent fiber glass reinforced nylon 12 as the nose/filler. The washers and end caps were zinc phosphated. The final construction is described in Section III, and the series were submitted to the sponsor for acceptance testing. Successful acceptance testing with these units is detailed herein.

ACCEPTANCE TESTING

Fifty-six units of the EG-B85-D configuration projectiles, R&D Series 120881-131, were submitted to the sponsor for acceptance testing. Testing was carried out at the BEF and Aeroballistic Research facilities at Eglin Air Force Base. In all testing, standard GAU-8/A aluminum cartridge cases and CIL 3331 propellant was used. For 160^{o}F testing, 141 grams of propellant were used, whereas for ambient and -65^{o}F testing 144 grams were used. Accuracy data were obtained at 2000 inches from the muzzle, and microflash photography was used where practical. Standard Aerojet TP projectiles in factory loads were used as warmer rounds and for comparative purposes. In addition, a small group of projectiles were cycled through the automatic gun system to determine their system compatability.

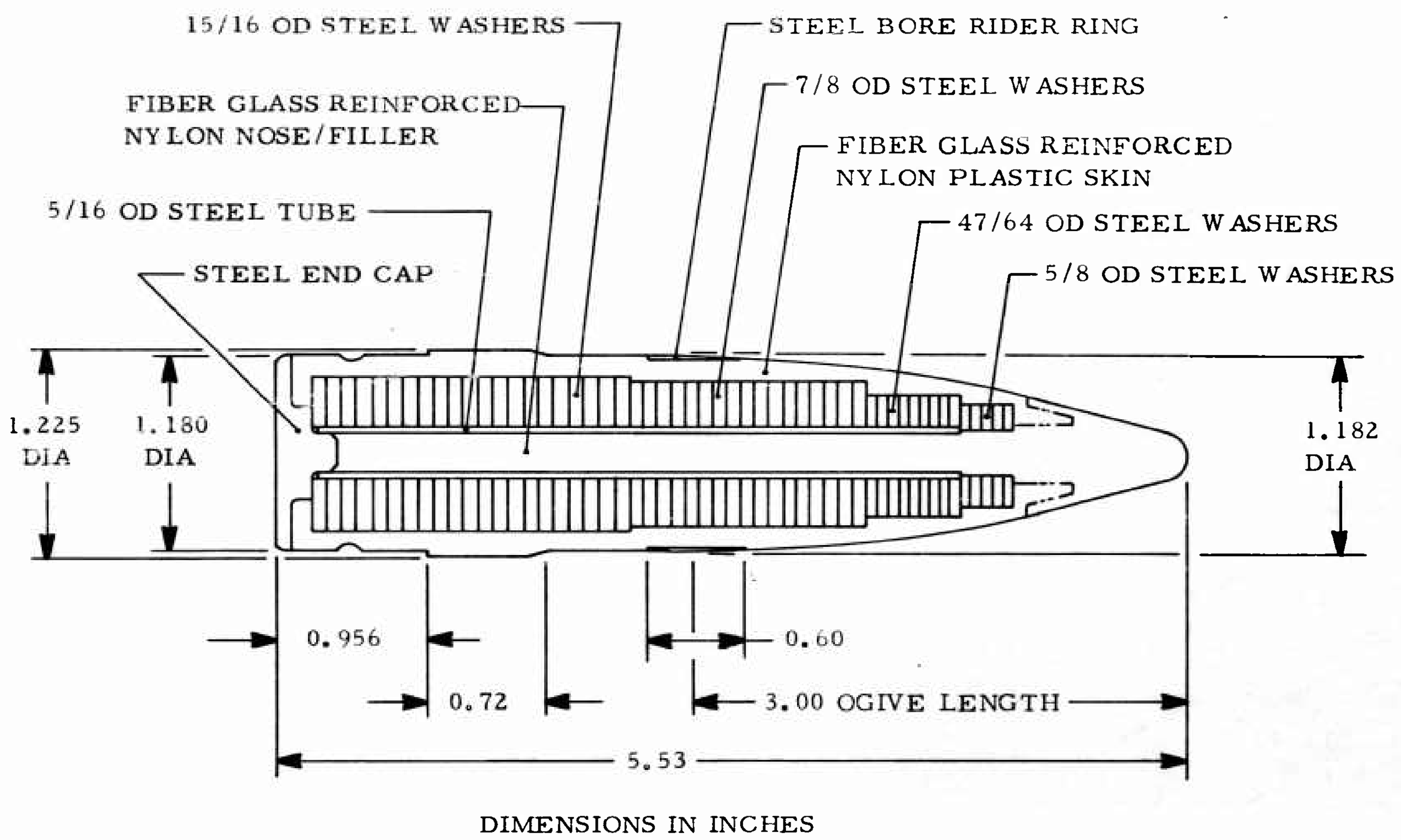


Figure 10. EG-B85-D Final Projectile Configuration

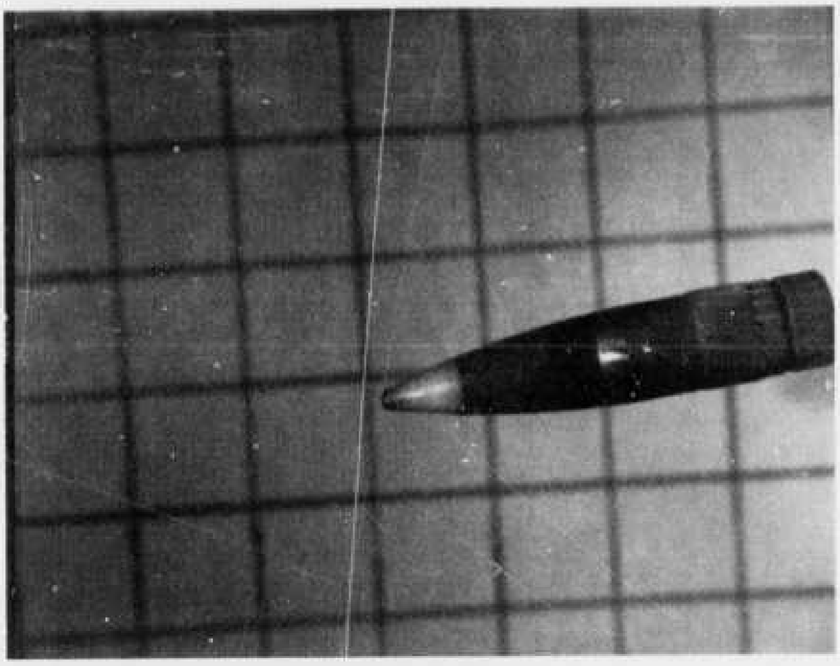


Figure 11. 120881-130 Series Frangible Projectile at $-65^{\circ}F$ and 3273 Ft/Sec Muzzle Velocity

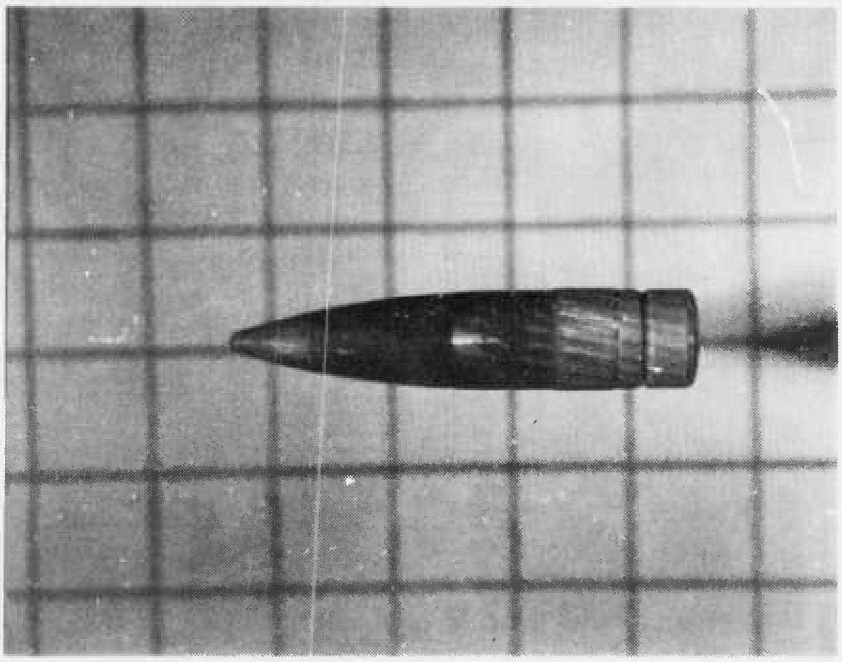


Figure 12. 120881-130 Series Frangible Projectile at $160^{\circ}F$ and 3434 Ft/Sec Muzzle Velocity

All frangible projectiles stayed intact during the firing trials, and met the accuracy requirement of a dispersion standard deviation of impact points about the mean impact point equal to or less than 0.70 milliradian. There was no evidence of rotating band fray. The test results are summarized in Table 5, and Figures 13 and 14 show microflash photographs of projectiles in flight at the temperature extremes. There was also no evidence of deleterious effects on the projectiles as a result of dry cycling in the automatic gun system.

For comparison purposes, standard Aerojet GAU-8/A TP projectiles were test fired concurrently with the acceptance lot of frangible projectiles, and their accuracy results are also presented in Table 5. The accuracy difference between the two types of projectiles tested was slight. However, considerable rotating band fray was evident (Figure 15). Its band fray, as well as the presence of unburned propellant, was also noticed by signature on the circuit paper used to start the velocity timers during the testing at the BEF facility.

The 30mm plastic frangible projectile, configuration EG-B85-D, was accepted based on the results of the testing.

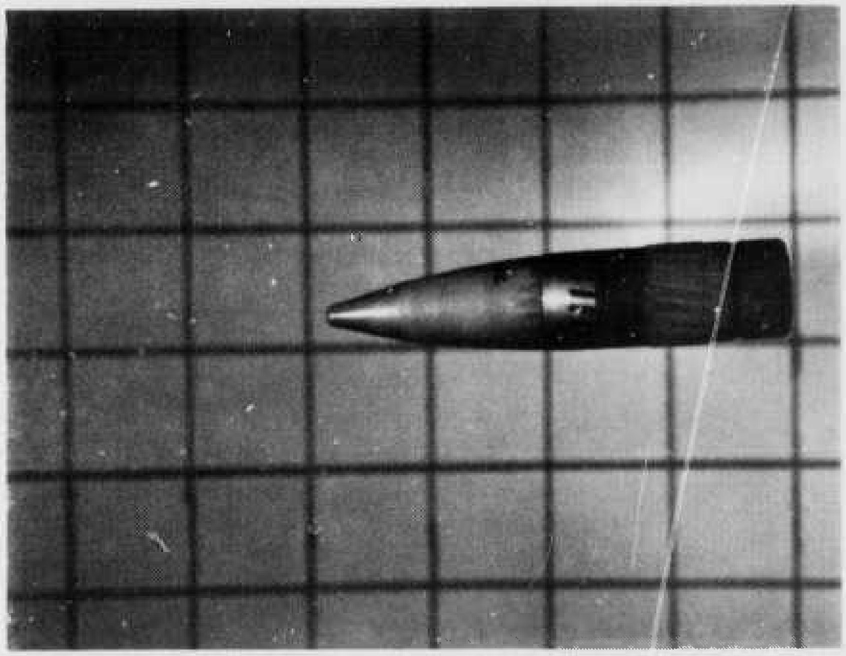


Figure 13. 120881-131 Series Frangible Projectile at -65°F and 3373 Ft/Sec Muzzle Velocity

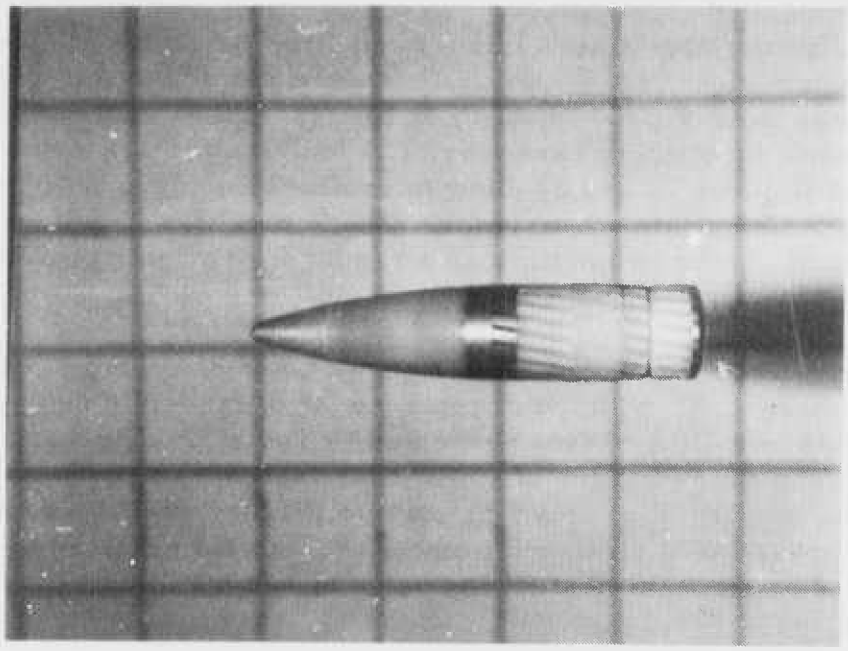


Figure 14. 120881-131 Series Frangible Projectile at 160°F and 3453 Ft/Sec Muzzle Velocity

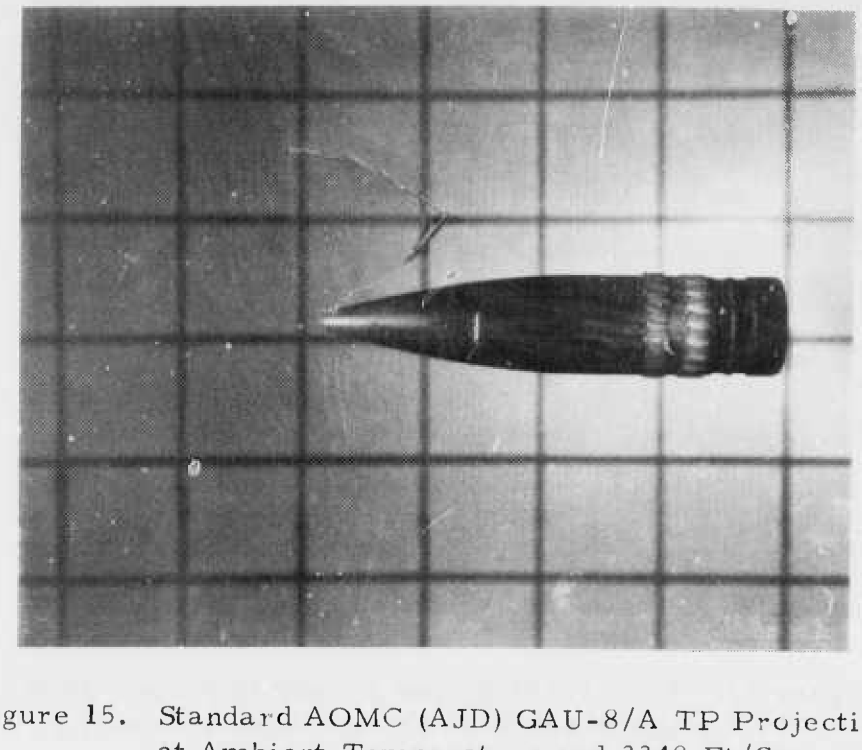


Figure 15. Standard AOMC (AJD) GAU-8/A TP Projectile at Ambient Temperature and 3348 Ft/Sec Muzzle Velocity

TABLE 5. ACCEPTANCE TEST FIRING RESULTS

Projectile Identification	Test Temperature (°F)	Sponsor Test Range	No. of Units	Chamber Pressure (kpsi)			Muzzle Velocity (ft/sec)			Accuracy Standard Deviation		
				Mean	Std. Dev.	Mean + 3 x Std. Dev.	Range	Mean	Std. Dev.	Horizontal (in)	Vertical (in)	Circular** (milliradians)
120881-131 R & D Series, EG-B85-D Configuration FTP	Ambient	BEF	17	57.9	2.8	66.3	3438 - 3806	3564	117	1.30	1.48	0.696
	160	BEF	8	58.3	2.5	65.7	3279 - 3742	3528	139	0.92	1.06	0.495
		Bay 10	11	64.7	1.5	69.2	3127 - 3509	3436	106	--	--	---
	-65	Bay 10	20	45.1	1.4	49.3	3223 - 3373	3325	36			
AOMC TP*	Ambient	BEF	6	43.7	1.8	48.9	3560 - 3912	3675	133	1.01	1.31	0.580
			10	50.4	2.9	59.2	3383 - 3440	3418	21	1.58	1.00	0.644

* Warmer and comparison rounds (two independent trials)

** The Circular Standard Deviation of accuracy is the average of the horizontal and vertical standard deviations of accuracy at 2000 inches, in accordance with the Aberdeen BRL method defined in Reference 5.

SECTION III

MANUFACTURING

At the conclusion of the development and acceptance test activities a quantity of 300 final design 30mm plastic frangible projectiles were manufactured. Of these, 100 were submitted in accordance with sponsor request to Amron Corporation for use in a program to develop an automatic roller crimping device, and the remaining 200 were shipped to the sponsor for their disposition. The details of the manufacturing activity are presented herein.

MATERIALS AND COMPONENTS

The materials and components used in the construction of the final design projectile consisted of four sizes of steel washers, a steel end cap, a steel bore-rider ring, a steel center tube, nylon 12 plastic in two levels of fiber glass reinforcement, and a high strength primer.

Washers

Four sizes of stamped steel washers were utilized, with their outer diameters selected on the basis of gradual transition into the ogive section, mass properties, and strength considerations of the outer plastic skin. The size details are presented in drawing EG-B85-D (see appendix). Although the washers have been procured from commercial washer manufacturers, the requirements have been that they have ID and OD tolerances of ±0.003 inch, a concentricity within ±0.005 inch, and that they be flat and free of edge burrs. The maintenance of the diametric tolerances is critical with respect to the dynamic balance and ultimate accuracy of the projectiles. For corrosion inhibition and for maximum primer adhesion the washers have been zinc phosphated in accordance with Federal Specification TT-C-490B in a fine grain, minimum weight coating.

End Cap

The end cap was manufactured from a leaded steel compatible with screw machine practices. The configuration is presented on drawing EG-B85-D, and the units have been zinc phosphated in accordance with Federal Specification TT-C-490B in a fine grain, minimum weight coating.

Center Tube

The steel center tube used in the construction is commercially available tube stock which is cut to length for incorporation into the projectile. No other processing other than cleaning is used in conjunction with the center tube.

Plastics

The basic plastic used in the construction is nylon 12; in particular, Huls L1801. The material is compounded with fiber glass reinforcement in two levels; 30 percent by weight for the outer skin and 50 percent by weight for the nose/filler. The 30 percent level was selected for the skin because of its compromise properties between high strength and toughness, and the 50 percent level was selected for the nose/filler for its resistance to molding sink. The materials are procured from Thermofil Corporation, their grade designations N9-3000 FG and N9-5000 FG for the 30 and 50 percent reinforcement levels, respectively. The materials are not colored.

Primer

The adhesive primer used for bonding the washer stacks and the end caps to the outer skin is an epoxy formulation procured from M&T Chemical Co., their product number 253-P. It is diluted for dip coating using M&T 200-T thinner. The application viscosity was 23 centipoise.

PROCESSING

The processing used in the manufacture of the EG-B85-D final configuration projectiles was virtually the same as was used in the previous work reported in Reference 1, with the addition of steps for the assembly and finishing of the bore-rider rings. The processing started with cleaning the zinc-phosphated steel washers in methyl ethyl ketone to remove any possible surface contamination present from handling. The cleaned washers were stacked in the array shown on the product drawing on the priming mandrels, locked in position, and dip coated in dilute M&T 253-P primer solution. After air drying to evaporate solvents, the primed washed stacks were baked in a 450°F circulating air oven for 45 minutes. After cooling, the edge bonded stacks were stripped from the mandrels and set aside for later use in outer skin molding.

In the outer skin molding process the edge bonded washer stacks were preheated to 300°F in a hot air oven before inserting them into the outer skin injection mold. Using Thermofil N9-3000 FG 30 percent fiber glass reinforced nylon 12, the outer skin was molded over the preheated washer stacks using a Buhler 200 ton, 6 ounce, reciprocating screw, injection molding press. The molding parameters and tooling were as reported in Reference 1.

Following the outer skin molding process the steel center tubes were hot vapor degreased in perchloroethylene and press fit within the ID of the washer stacks. This assembly was then inserted within the nose/filler mold, and the nose and filler were injection molded through the tube ID using Thermofil N9-5000 FG 50 percent fiber glass reinforced nylon 12. To assist in providing a hermetic seal, the interface area of the outer skin was flame treated prior to this molding operation. The Buhler 200 ton press described previously and the mold tooling described in Reference 1 were used in this operation.

The zinc-phosphated steel end caps were cleaned in methyl ethyl ketone, dip primed in dilute M&T 253-P primer, air dried to evaporate solvents, and baked in a 450°F circulating air oven for 35 minutes. After cooling, the prepared units were stored for the bonding operation with the outer skin. In the bonding operation the prepared end caps were positioned on the rear of the projectiles, and the unfinished subassemblies were positioned over a conical plate coil attached to a 5-KW radio frequency generator. Using three 5-second power bursts with 1-second delays between bursts the tailpieces were induction bonded to the projectiles. A power level of 100 milliamperes (no load) grid current was used, and the bonded end caps were quenched in water after processing.

The washer stacks were induction bonded to the outer skin in an identical manner as reported in Reference 1. The unbounded projectile was placed within a multi-turn induction coil affixed to a 5-KW radio frequency generator, with the projectile base (steel tailpiece) resting on a water pedestal. The water pedestal was used to remove heat from the already bonded end cap without damaging or otherwise deleteriously affecting its bond. Bonding was accomplished in a 23-second, 150-milliampere (no load) grid current power cycle while rotating the projectile inside the coil. Rotation was used to provide uniform heating within the discontinuous stack of washers. After heating, the projectiles were cooled in a cold water bath to transfer the heat from the fully contained washer stacks.

At this stage of the operations the projectiles were dimensionally inspected. The diameter of the bourrelet, the diameter of the rotating band, the overall length and the tailpiece radial eccentricity were measured. Typical values from the production lot are indicated in Table 6.

TABLE 6. RESULTS OF DIMENSIONAL INSPECTION,

PRODUCTION PROJECTILES

Dimension	Range	Mean	Standard Deviation
Rotating Band Diameter	1.223 - 1.226	1.2247	0.0005
Bourrelet Diameter	1.181 - 1.183	1.1820	0.0006
Tailpiece Radial Eccentricity	0.000 - 0.015	0.0052	0.0030
Overall Length	5.525 - 5.540	5.532	0.0032
(Dimensions are in inches)			

After the dimensional inspection and the rejection of units for oversize bourrelets and excessive end cap radial run-out, the units were chucked in a lathe, indicated, and adjusted for nose run-out within 0.001 inch. The bore-rider ring seat was then machined, and the ring was press fit to the seat. An interference fit of 0.003 inch was used. The projectiles were reindicated for nose run-out within 0.001 inch, and the contour of the ring was machined. The machined surfaces of the ring were coated with a black automotive primer for corrosion protection, and mass properties of the units were measured. The mass property measurements are shown in Table 7.

A cutaway view of the production projectiles is shown in Figure 16. Finished projectiles were shipped to the sponsor for test and to Amron Corporation, under sponsor direction, for use in crimping machine development. A crimped projectile is shown in Figure 17.

TABLE 7. MASS PROPERTIES OF PRODUCTION PROJECTILES

Property	Range	Mean	Standard Deviation
Weight, grams	353.80 - 356.57	355.22	0.83
Polar Moment of Inertia, lb-in^2	0.0968 - 0.0978	0.0974	0.00035
Transverse Moment of Inertia, lb-in^2	1.235 - 1.256	1.243	0.0075
CG from Nose, inches	3.482 - 3.542	3.530	0.012

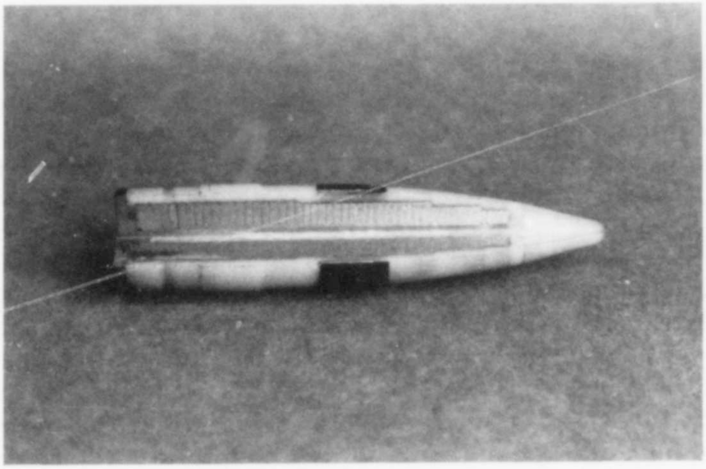


Figure 16. Cutaway View of Production Projectile

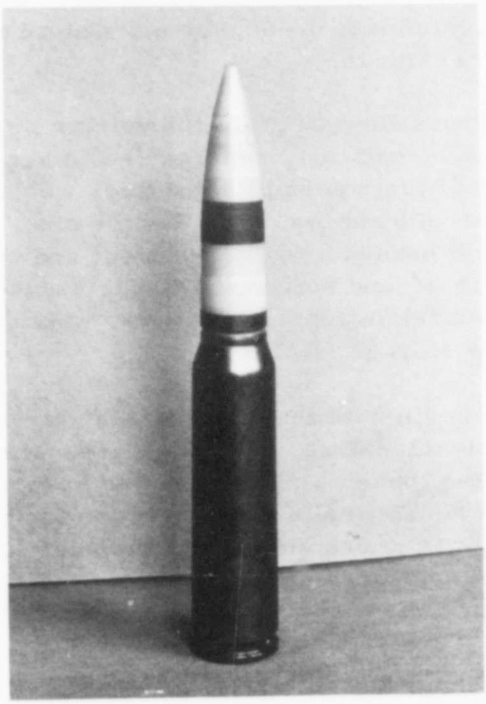


Figure 17. Frangible Projectile Crimped to Cartridge Case

SECTION IV

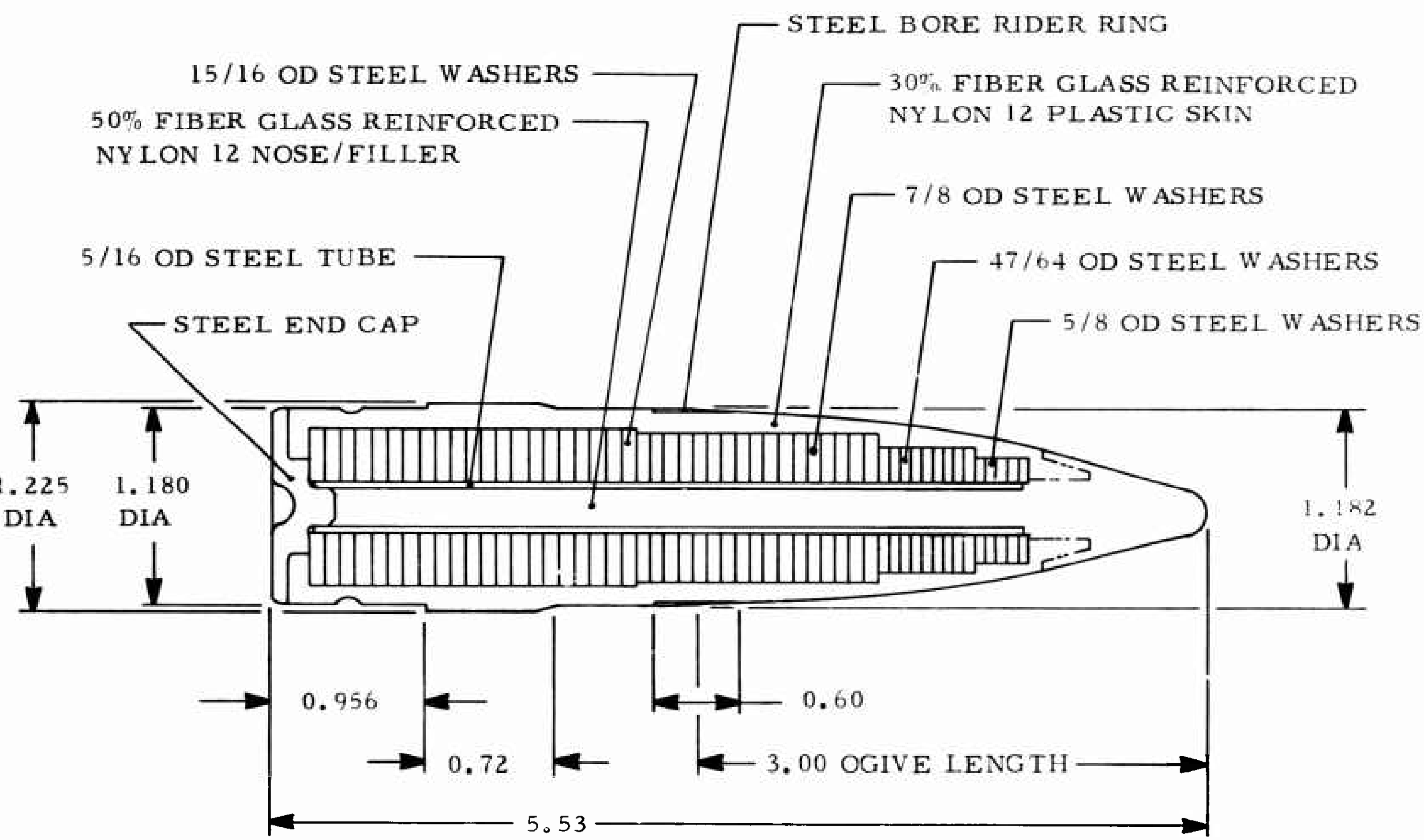
MANUFACTURING PROJECTIONS

A 30mm washer stack frangible projectile has been developed which meets all requirements for structural integrity and accuracy. It does, however, have some problems associated with manufacturing, but sufficient experience has been gained in this program which will permit the projection of resolution of these problem areas. For instance, it is felt that center tube stock can be procured in which the ID to OD eccentricity can be controlled within acceptable limits. Through process and assembly equipment development the radial and longitudinal run-out of the end caps is also expected to be controlled. The tailpiece would also be reconfigured to be consistent with either cold heading or powder metallurgy processing. (See Figure 18.)

It is assumed, for the purposes of this analysis, that the manufacturing activity would be accomplished within an existing factory having plastics and assembly expertise, and that this factory would procure all metal parts ready for plastics processing. Buildings for housing the operation are assumed to be available. In keeping with the requirements of the previous contract, manufacturing projections based on these assumptions are presented for an annual volume of 3,480,000 units at an average rate of 290,000 projectiles per month.

The operations and cross flows thereof for volume manufacturing of 290,000 units per month are schematically represented in Figure 19. The procurement staff, as a part of their normal activities, would annually purchase phosphated punched steel washers, steel center tubes, steel bore-rider rings, phosphated cold headed or sintered steel end caps, fiber glass reinforced plastic, primer, and solvents. These would be delivered to existing warehouse space, except the plastics, which would be pumped from rail cars to new storage silos.

Manufacturing would begin with the bulk transfer of washers, center tubes, and end caps to the cleaning area, where six separate slack chain conveyors would transport the loose parts through the appropriate cleaning baths. One large tank would house five of the conveyors for ketone rinsing of washers and tail plugs, and one smaller tank would accommodate the conveyor for the hot vapor degreasing of the center tubes. The parts would be conveyed through appropriate drying tunnels, and chuted to feed bins of the next operation. One man, working on first shift only, would operate the cleaning station, including weighing, loading, solvent replenishment, and handling washers at a rate of 40 lb/min. A circulating floorman would expend a part of his time on this shift stocking the area with a daily supply of



DIMENSIONS IN INCHES

Figure 18. Mass Production Projectile Concept

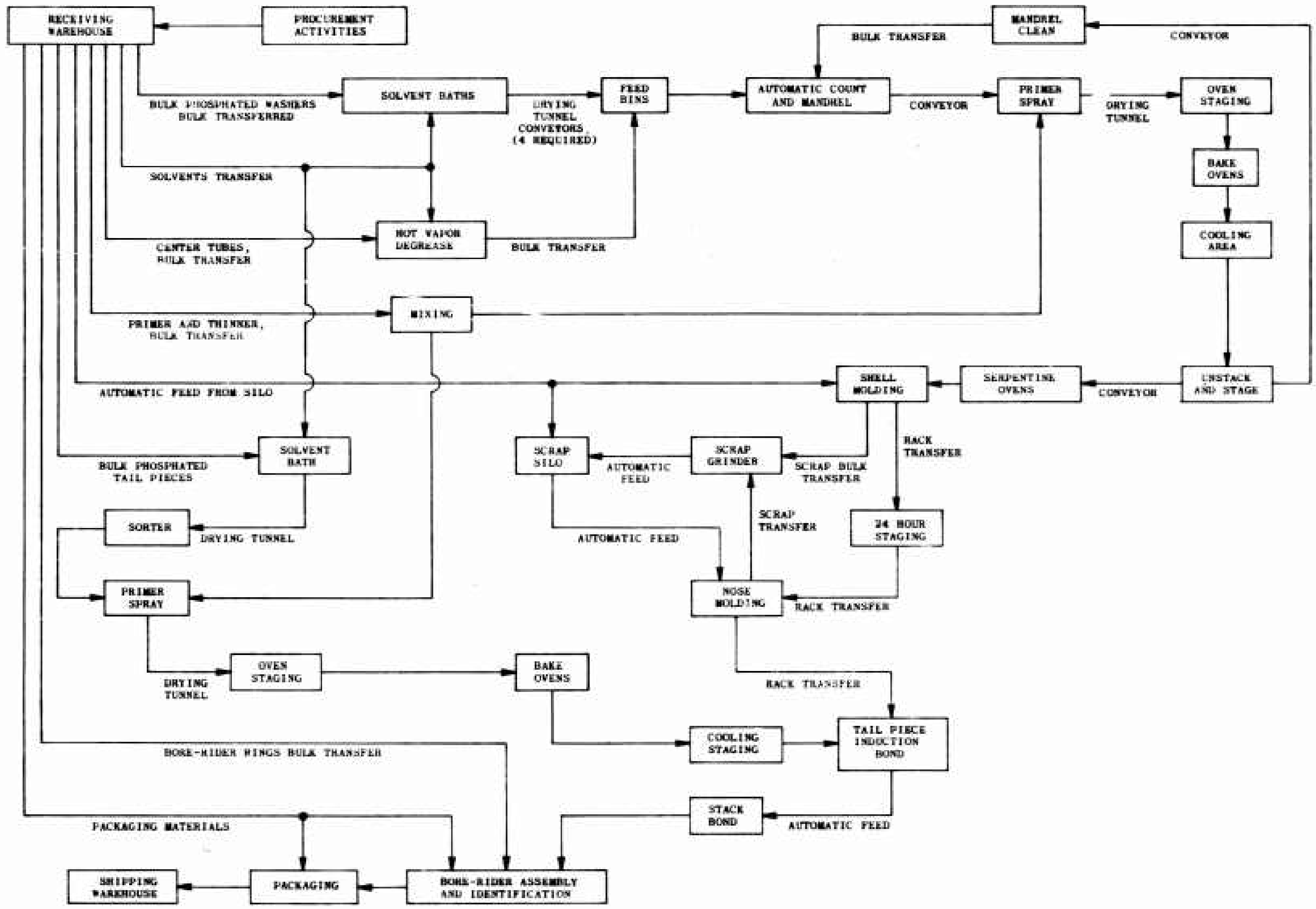


Figure 19. Manufacturing Flow Diagram

parts. Washers and center tubes from the feed reservoirs would be automatically fed to chutes on the mandrel loading equipment. The mandrels, automatically fed to the equipment from a separate reservoir, would index at each station, where, in this order, the center tubes, 15/16-inch, 7/8-inch, 47/64-inch, and 5/8-inch OD washers would be assembled. The final indexing station would lock the assembled stacks onto the mandrels. One attendant on one shift would oversee the 40 stack per minute operation.

The stacked washers, while mandreled, would advance to an automatic spray booth where the exterior surface would be sprayed with dilute 253-P primer while rotating at the index station. The following station would blow air at the revolving stack to smooth out the coating. The primed stacks would then travel through a drying tunnel for solvents evaporation, followed by automatic pick-off and loading onto oven racks. One operator on one shift would oversee this operation, including moving the filled oven racks and maintaining primer supply. One circulating floorman would expend part of his time on the first shift only preparing and transporting primer.

The loaded racks of washers, after accumulation in the staging area, would be loaded onto carts for oven baking. A 30-minute oven load of 1200 stacks would be loaded into the forward door of the gas fired baking oven for its 30-minute cycle of 450°F. After 30 minutes the next load would be inserted, pushing the former load into the cooling staging area. One oven attendant on one shift would handle this operation.

Another attendant would unload the oven racks and load the stacked mandrels onto an infeed conveyor to the outer shell molding area. At the first station the stacks would be unlocked, followed by stripping of the mandrels at the next station. A third station would out-feed the now bonded washer stack onto the conveyor to the serpentine preheating oven. A circulating floorman would recycle oven carts and stacking mandrels to each station on a part-time basis.

The recycled mandrels would require occasional cleaning involving wire brushing and hot solvent immersion. One operator on one shift would accomplish this operation.

For the outer shell molding, rotary presses with one each mold set of 16 cavities would be used, with one operator per machine on each of three shifts. The operator would load a 16 cavity molding board, load the mold, cycle one set of cavities, unload the previous set of cavities and recycle. Semi-finished projectiles would be moved from the press area for cooling by a part-time floorman. The operator would also cycle molding scrap into the grinder, and the floorman would cycle the ground scrap to the accumulator silo.

After a 24-hour holding period the molded outer shell and washer stack assemblies would be rack transferred to the nose molding area, where a 16 cavity mold set and rotary presses would be used for molding. One operator on each of 3 shifts would function in a manner similar to that of the outer shell molding. The racks of semi-finished projectiles would be moved to the bonding area by the part-time floorman. Prior to bonding, however, the previously cleaned end caps, after emerging from the cleaning bath and drying tunnel, would be spray primed and baked in a manner similar to the washer operation and with the same personnel. The primed end caps would be moved in bulk to the induction bonding area, where they would be fed to the hoppers.

The hoppers would feed two lines of projectiles, automatically installing the end caps onto the projectiles. Projectiles would be indexed in groups of five on each line for end cap bonding, followed by a 15-second hold and quench cycle in the next station. A take-off would remove the projectiles and invert them into a synchronized second set of conveyors, which in turn would index them under the washer bonding coils. The projectiles would be lifted through the coils and bonded, retracted, and deconveyed at the next station into a quench bath. A lift conveyor would remove the projectiles from the quench bath and deposit them to a third conveyor to transport them through a drying tunnel. At the end of the tunnel automatic descramblers and lead screws would position the projectiles for fitment with the bore-rider rings. One attendant on one shift would monitor this fully automatic operation.

Prepainted bore-rider rings would be fed to fitment and printing press. Projectiles from the bonding operation would be automatically fed to the equipment, and the bore rider rings would be pressed in place. In the next station the units would be identified automatically on the surface of the ring and shuttled to a packing table. The units would be packaged in 30-round (25 lb) cartons, and the cartons would be roller conveyed to the shipping warehouse. One attendant would oversee the operation, and a part-time floorman would assist in package movement. Both persons would be on a one shift basis.

Throughout the operation inspectors would be utilized to insure the quality of the finished projectiles. On the first shift, which encompasses all operations, two inspectors would be utilized full time. They would rove all operations, and inspect by attributes critical molding and assembly areas. On the second and third shifts, which encompasses only molding, roving floor inspectors, as a part of their normal duties in a plastics factory, would oversee the molding operations of the outer skin and nose/filler. Approximately 12. 5 percent of their time is expected to be expended in these activities.

Based on the materials and processes delineated herein cost projections can be generated. A detailed cost analysis is presented in Table 8, and shows that an equipment investment of approximately $1,075,000 would be required to support the program. From this, a unit cost of $1.104 would result. Allowing a 20 percent return on investments and working capital (inventory, average work in progress, and accounts receivable), the unit cost would increase to approximately $1.207.

TABLE 8. COST ANALYSIS - 290,000 UNITS PER MONTH

Equipment Investment:

1	Regrind accumulator system		$ 10,000
2	Silos, with conveyors and driers		78,000
2	Forklift trucks		11,000
4	Pallet trucks		2,000
6	Cleaning conveyors		30,000
3	Cleaning tanks		15,000
3	Cleaning tank exhaust systems		15,000
5000	Priming mandrels		10,000
1	Mandrel stacking machine		34,000
1	Washer spray priming machine		15,000
1	Priming exhaust equipment		5,000
1	Washer drying tunnel		3,000
1	Washer pick-off equipment		5,000
10	Oven carts		10,000
500	Oven racks		6,000
2	Gas ovens		20,000
1	Mandrel stripping machine		10,000
3	Serpentine ovens		45,000
2	Rotary presses		90,000
1	Outer shell mold set		35,000
1	Nose/filler mold set		25,000
1	Loading board		1,000
1	Scrap grinder		3,500
1	3-station thermolator		3,500
1	1-station thermolator		1,000
1	Tailpiece spray priming machine		10,000
2	Tailpiece bonding conveyors		40,000
2	Washer bonding conveyors		60,000
4	RF Generators - 40 KW		80,000
1	Bonding take-off and drying tunnel		10,000
1	Bore rider ring press and identification line		15,000
1	Roller conveyor		5,000
AR	Inspection tools and equipment		10,000
AR	Miscellaneous equipment		25,000
		Sub-Total	738,000
	Installation, 20 percent of 738,000		147,600
		Sub-Total	885,600
	Engineering, 10 percent of 885,600		88,560
		Sub-Total	$974,160

TABLE 8. COST ANALYSIS - 290,000 UNITS PER MONTH (Continued)

Equipment Investment:

	Sub-Total	$ 974,160
Contingencies, 5 percent of 974,160		48,708
	Sub-Total	1,022,868
Freight & Sales Tax, 7 percent of 738,000		51,660
Total Investment		$1,074,528
Depreciation - 5 year straight line		214,906

Floor Space Requirements

Manufacturing	6,000 ft^2
Warehousing	12,000 ft^2

Variable Expense

Direct Labor

First Shift

3 Floormen at 2.50/hr	=	7.50	
5 Attendants at 3.00/hr	=	15.00	
5 Operators at 3.50/hr	=	17.50	
2 Inspectors at 5.00/hr	=	10.00	
1 Foreman at 6.50/hr	=	6.50	
16 Persons		56.50/hr	
2000 hours at 56.50/hr			113,000
Maintenance DL at 1 percent of 1,074,528			10,745
			123,745

Second Shift

2 Operators at 3.50/hr	=	7.00	
1/8 Floorman at 2.50/hr	=	.31	
1/8 Inspector at 5.00/hr	=	.63	
		7.94/hr	
2000 hours at 7.94/hr			15,880
Maintenance DL at 0.125 percent of 1,074,528			1,343
			17,223
Shift Premium - 5 percent			861
			18,084

TABLE 8. COST ANALYSIS - 290,000 UNITS PER MONTH (Continued)

Variable Expense			
Direct Labor			
Third Shift			
DL same as Second Shift		17,223	
10 percent shift premium		1,722	
		18,945	
Total Direct Labor			$160,774
Fringe Benefits - 30 percent of $160,774			48,232
Raw Materials			
Phosphated Washers			
15/16 OD x 0.095 thick:			
3,480 M units at 21 each	73,080 M		
Scrap & Loss - 0.25 percent	183 M		
	73,263 M		
at 8.20/M x 73,263 M =		600,535	
7/8 OD x 0.084 thick:			
3,480 M units at 17 each	59,160 M		
Scrap & Loss - 0.25 percent	148 M		
	59,308 M		
at 6.46/M x 27,979 M =		383,130	
47/64 OD x 0.062 thick:			
3,480 M units at 7 each	24,360 M		
Scrap & Loss - 0.5 percent	122 M		
	24,482 M		
at 3.22/M x 24,482 M =		78,832	
5/8 OD x 0.060 thick:			
3,480 M units at 5 each	17,400 M		
Scrap & Loss - 0.5 percent	87 M		
	17,487 M		
at 2.28/M x 17,487 M =		39,870	
Bore-Rider Ring, Fabricated and Painted			
3,480 M at 1 each	3,480 M		
Scrap & Loss - 0.5 percent	17 M		
	3,497 M		
at 0.10 each x 3,497,000		349,700	

TABLE 8. COST ANALYSIS - 290,000 UNITS PER MONTH (Continued)

<u>Raw Materials</u>			
Phosphated End Cap			
3,480 M at 1 each	3,480 M		
Scrap & Loss - 0.50 percent	17 M		
	3,497 M		
at 0.06 each x 3,497,000		$ 209,820	
Center Tube			
Same Cost Factor as End Cap		209,820	
Plastics			
3,480 M at 0.15 lb. each	522,000 lb.		
Scrap & Loss - 0.5 percent	2,610 lb.		
	524,610 lb.		
at 2.25/lb x 524,610		1,180,373	
Primer			
Volume required	400 gal.		
Losses	400 gal.		
	800 gal.		
800 gal. at 10.00 gal.		8,000	
Solvents - 1500 gal. at 10.00/gal.		15,000	
Packaging Materials			
116,000 cartons at 0.27 each		31,320	
Total Raw Materials			$3,106,400
<u>Utilities</u>			
2500 KW at 2,000 hrs.	= 5,000,000 KWH		
500 KW at 4,000 hrs.	= 2,000,000 KWH		
	7,000,000 KWH		
at $0.025 KWH			175,000
Maintenance Supplies -1.25 percent of 1,074,528			13,432
Other Variable Expenses			---
Total Variable Expense			$3,503,838

TABLE 8. COST ANALYSIS - 290,000 UNITS PER MONTH (Continued)

Fixed Expenses				
Indirect Labor				
50 percent of Manager	at	25,000 =	12,500	
25 percent of Purchasing Agent	at	15,000 =	3,750	
50 percent of Purchasing Clerk	at	6,000 =	3,000	
50 percent of Manufacturing Engineer	at	15,000 =	7,500	
10 percent of Warehouse Foreman	at	10,000 =	1,000	
Maintenance IL at 1.25 percent of 1,045,408		=	13,068	
				$ 40,818
Fringe Benefits - 30 percent of 40,818				12,245
Depreciation				214,906
Insurance & Taxes - 3 percent of 1,074,528				32,236
Maintenance Supplies - 1.25 percent of 1,074,528				13,432
Space Charges				
6,000 ft^2 at 2.00/ft^2			12,000	
12,000 ft^2 at 1.00/ft^2			12,000	
				24,000
Other Fixed Expense				--
Total Fixed Expenses				$ 337,637
Total Manufacturing Cost				$3,841,475
Unit Manufacturing Cost			$1.104	
20% Return on Investment				214,906
Returns on Working Capital:				
20 percent on raw materials inventory 30-day supply			51,997	
20 percent of 15-day work in progress			29,199	
20 percent of 30-day accounts receivable			64,025	
				145,221
Total Manufacturing Cost plus Returns Before Taxes				$4,201,602
Unit Cost			$1.207	

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

It has been demonstrated that the 30mm plastic frangible projectile, based on the concept of encapsulating steel washers with fiber glass reinforced nylon 12, may have the capability of meeting all requirements for structural integrity and accuracy in GAU-8/A ammunition.

It was further demonstrated, however, that certain problem areas exist which can be detrimental to projectile performance. These were the radial and longitudinal eccentricities of the steel end cap and the ID/OD eccentricity of the steel center tube. Each has been demonstrated to result in structural break up and inaccuracy. It is recommended that, if development work is continued, supply sources for straight and accurately concentric tube stock, dimensionally accurate washers and end caps, along with assembly techniques for best utilizing such materials, be investigated. Since the production cost impact of using higher precision components cannot be favorable, cost/performance trade-offs will become especially important.

Although the basic goals of this contract have been met, the fundamental goal of the design concept--replacing complicated metal forming and machining operations with simple metal stamping and plastic injection molding operations--has not yet been fully achieved.

REFERENCES

1. Steidley, R. B., DeBell & Richardson, Division of Springborn Laboratories, Inc., Enfield, Connecticut, and Bilsbury, S. J. Air Force Armament Laboratory, "Development of a 30mm Plastic Frangible Projectile", Technical Report AFATL-TR-75-137, October, 1975.

2. "Prime Item Specification for Cartridge, 30mm, PGU-15/B", Specification A10146B, 28 October 1974.

3. Steidley, R. B., DeBell & Richardson, Division of Springborn Laboratories, Inc., Enfield, Connecticut, "Development of Plastic Materials for 20mm Plastic Rotating Bands", Technical Report AFML-TR-76-195, December, 1976

4. Henson, J. R., Patton, J. B., and Seiber, B. L., Arnold Engineering Development Center, Tennessee, "AFATL/GE GAU-8/A Materials Test", Test Report AEDC-DR-76-16, March, 1976.

5. Groves, A. D., Ballistics Research Laboratory, Aberdeen Proving Ground, "Handbook on the Use of the Bivariate Normal Distribution in Describing Weapons Accuracy", Memorandum Report 1372, September, 1961.

APPENDIX

DRAWING EG-B85-D
ASSEMBLY, 30MM FRANGIBLE PROJECTILE

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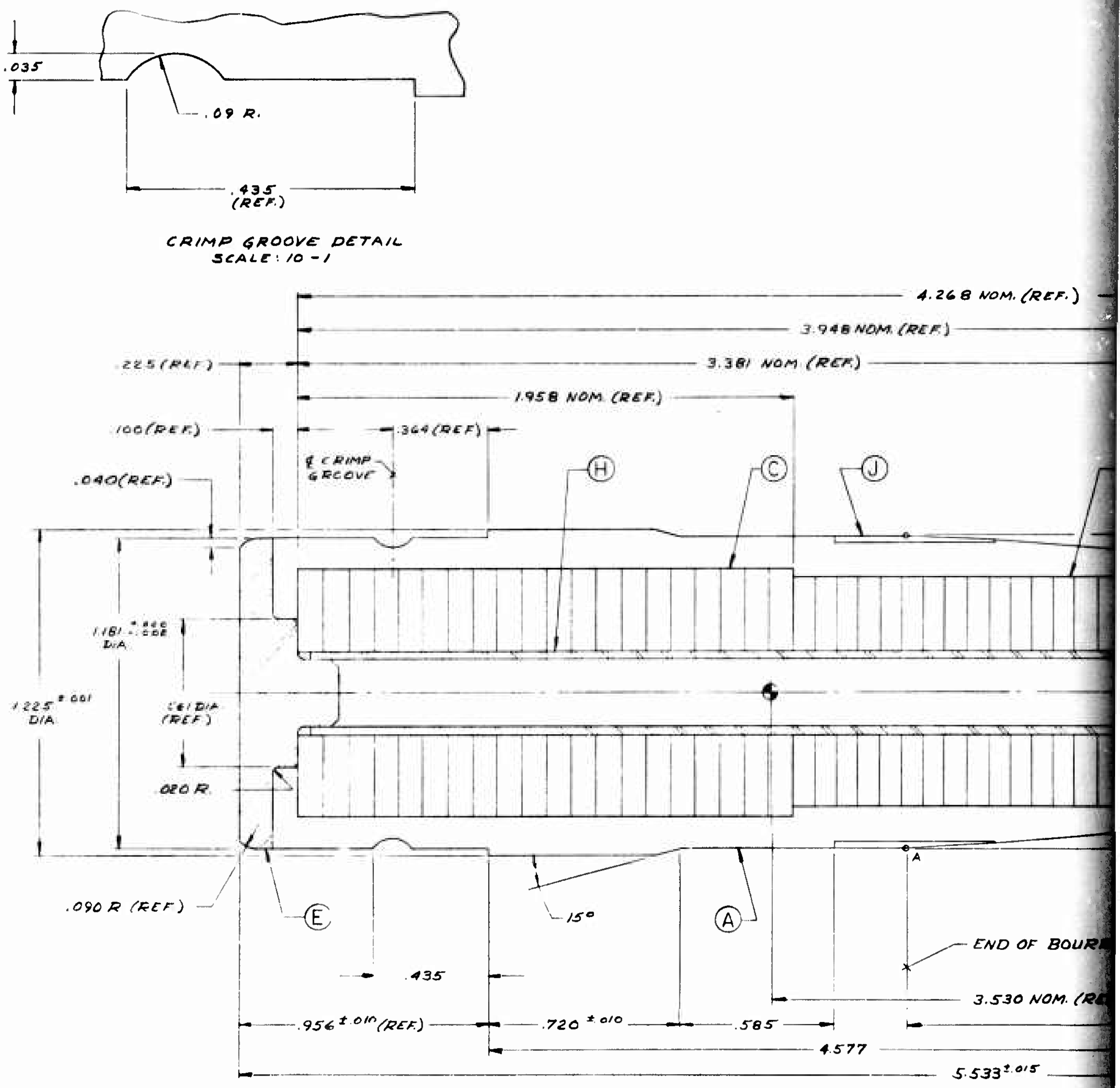
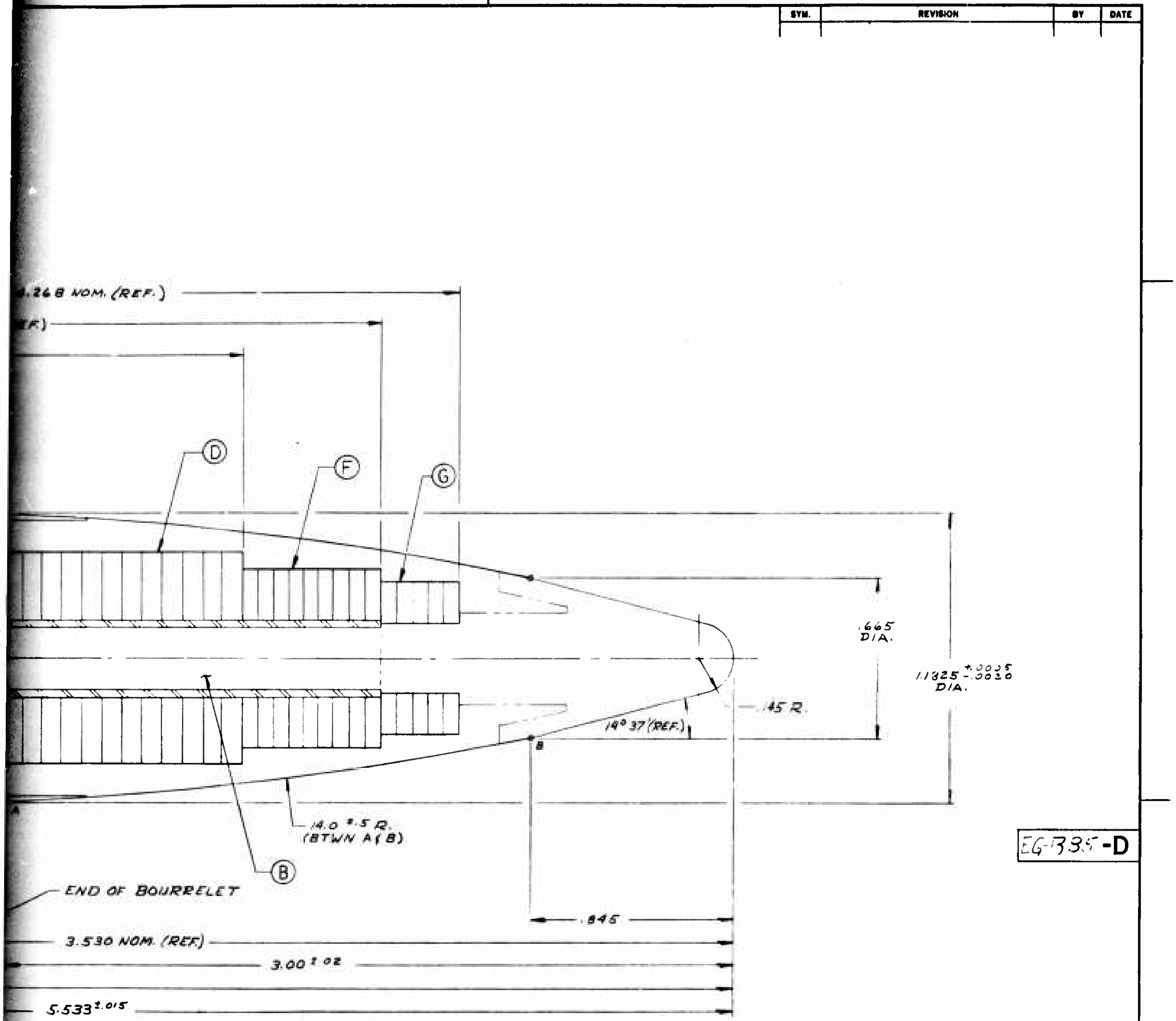


NOTES:

1. MFR PER D&R LOG PP. 120881-120883
2. QTY OF WASHERS MAY VARY ± 1 WASHER PER ITEM
3. WEIGHT: 5480 ± 50 GRAINS
4. USED ON 120881-131 SERIES & SUBSEQUENT



ITEM	REQ'D.	PART NO.	DESCRIPTION	MATERIAL	STOCK SIZE
J	1	EG-879-B2	BORE RIDER	STEEL	
H	1	EG-861-B3	INNER LINER	STEEL	
G	5	MS-27183-10	WASHER	STL, $ZnPO_4$ COATED	.625 O.D. x .281 ID x .064
F	9	MS-27183-11	WASHER	STL, $ZnPO_4$ COATED	.734 OD x .312 ID x .063
E	1	EG-857-B4	BUTT PLUG	STEEL	
D	17	-9	WASHER	STL, $ZnPO_4$ COATED	.875 OD x .312 ID x .084
C	21	-7	WASHER	STL, $ZnPO_4$ COATED	.938 OD x .312 ID x .093
B	1	-5	NOSE / CORE	50% GR NYLON 12	THERMOFIL N9-5000 FG
A	1	-3	OUTER SHELL	30% GR NYLON 12	THERMOFIL N9-3000 FG

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED SCALE 4-1 TOLERANCE ON FRACTIONS ±1/64 TOLERANCE ON DECIMALS ±.005 TOLERANCE ON ANGLES ±1/2°	ASSEMBLY - 30 MM FRANGIBLE PROJECTILE		DEBELL & RICHARDSON, INC. HAZARDVILLE, CONN.
	MATERIAL SPEC.	DRAWN TEZ DATE 9-20-76 CHECKED DATE	ENG. APPROVAL EG-B85-D

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TAC/DRA	1
Hq SAC (NRI/STINFO LAB)	1
WRAMA/MMEBL	1
AFWL/LR	2
AUL/LSE 71-249	1
Redstone Sci Info Cntr/Doc/Sec	2
Lib, K2400, Frankford Arsenal	1
USN Weapons Lab	1
NSWC/Tech Lib/White Oak	2
Nav Ord Stn/Tech Lib	1
USN Wea Cntr/Code 233	2
AFWL/Tech Lib	1
NASA Stinfo Fac/Acquisitions Br	1
The John Hopkins Univ/App Physics	2
Battelle Memorial Inst/Reports Lib	2
The Rand Corp/Lib-D	1
DDC/TC/Accessions Div	2
Ogden ALC/MMWMP	2
AEDC/ARO, Inc	2
Hq PACAF/LGWSE	4
USAFTAWC/TX	1
AFATL/DL	1
AFATL/DLDG	20
Springborn Laboratories, Inc.	10
AFATL/DLODL	9
AFATL/DLYV	1
AFATL/DLDL	1
AFATL/DLDA	3
AFATL/DLDE	1
AFIS/INTA	1
ASD/ENESS	1
AFATL/DLJ	2
AFATL/DLA	1
Hq USAFE/DOQ	1
Hq PACAF/DOOFQ	1
NSWC/DL	1
AFATL/DLODR	1
TAC/INA	1
ASD/XRP	1
US Army TRADOC Sys Analy Act/ ATAA-SL	1
COMIPAC/I-232	1

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